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INFRARED SPECTROSCOPY TECHNOLOGY AND ITS APPLICATIONS IN TEXTILE RECYCLING

Improving Sustainability in the Clothing Industry through Infrared Spectroscopy Technology

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ABSTRACT

The textile industry is the oldest branch of consumer goods manufacturing, it is a diverse and heterogeneous sector which consume natural resources to fulfil the requirements. Virgin and raw materials are required to make new clothes and textiles. The production of virgin fibres while utilizing natural resources are not efficient and environmental friendly in anyway. Thus, to meet the present and future demand of textile managing textile’s waste and recycling it in efficiently is demand at the moment. To make textile recycling industry more efficient and sustainable, technological advancement and its implementation is required for textile recycling. There are various technologies have been used in the area of textile’s industry.

Infrared spectroscopy has been widely used in the textile industry, spectral analysis has sensitivity and accuracy to analyse textile fibres based on qualitative and quantitative techniques. There is a need to improve the infrared technology based applications to sort and recycle textile in sustainable technique. Although, the volume of textile waste is expanding rapidly and increasing co2 due to textile landfill, in the result these negative impacts of landfill damaging the environment. This research investigates the viable way to implement infrared technology applications for textiles sorting and further developments in the developed technology.

The current textile waste collection methods, recycling and sorting textile’s based on their fibres has been investigated, while the Dutch state of the art technology have been considered due to its efficient textile waste handling system. Sorting fibres and textiles based on their composition of materials is the recently developed technology. Textile4Textiles and FIBRESORT machines are the best innovations for sorting textiles. In the developed system for textile’s sorting, there is a room for further developments on the large commercial scale for sorting textile automatically.

Circular economy is the definition of closed loop or sustainable development. However, in the process of developing FIBRESORT machine and the partners of the project have opportunities to develop new business models based on these technology.

Keywords: Sustainable textiles, Infrared in textiles. Fibres, Recycling, Spectroscopy

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TIIVISTELMÄ

Tekstiiliteollisuus on kulutustuotteiden valmistuksen vanhin toimiala, se on monipuolinen ja heterogeeninen ala kuluttaessaan tarpeitaan vastaavia luonnonvaroja. Uuden kuidun tuotanto luonnonvaroja käytettäessä ei ole millään tavalla tehokasta eikä ympäristöystävällistä. Siispä tällä hetkellä on hyvin ajankohtaista tekstiilijätteen ja kierrätyksen tehokas hallinta, jotta nykyinen ja tuleva vaatimustaso tekstiileissä kohtaavat. Jotta tekstiiliteollisuudesta voidaan tehdä tehokkaampaa ja ympäristöä säästävämpää, tekstiilien kierrätysmenetelmien kehittäminen ja niiden toteutus on tarpeen. Tekstiiliteollisuuden alalla on käytetty useanlaisia menetelmiä.

Infrapunaspektroskopiaa on käytetty laajalti tekstiiliteollisuudessa, spektrianalyysi on herkkä ja luotettava tekstiilikuitujen analyysi perustuen kvalitatiiviseen ja kvantitatiiviseen tekniikkaan. Infrapunatekniikkaan perustuvien sovellusten parantamista tarvitaan ympäristöystävällisien menetelmien kehittämisessä tekstiilien lajittelussa ja kierrätyksessä. Sitäpaitsi tekstiilijätteen määrä on lisääntymässä nopeasti ja hiilidioksidin määrä lisääntyy tekstiilien päätyessä kaatopaikalle, mikä johtaa kaatopaikkojen ympäristötuhojen negatiiviseen vaikutukseen. Tämä tutkimus selvittää mahdollisia keinoja käyttää infrapunateknologiasovelluksia tekstiilien lajittelussa sekä jo kehiteltyjen menetelmien jatkokehittelyä.

Nykyisiä menetelmiä kerätä tekstiilijätettä, kierrättää ja lajitella tekstiilejä perustuen niiden kuituihin on tutkittu, samoin on punnittu hollantilaista huippuluokan teknologiaa tehokkaana tekstiilijätteen käsittelymenetelmänä.

Kuitujen ja tekstiilien lajittelu perustuen niiden materiaalien yhdistelmiin on hiljattain kehitetty menetelmä. Textile4Textiles ja FIBRESOFT -koneistot ovat parhaat innovaatiot tekstiilien lajittelussa. Jo kehitellyssä tekstiilien lajittelumenetelmässä on tilaa tekstiilien automatisoidun lajittelun laajan mittakaavan kaupalliselle kehittämiselle.

Kiertotalous määrittelee ympäristöystävälliselle kehitykselle suljetun kierron. Kuitenkin FIBRESOFT- koneiston kehittelyprosessilla ja sen projektiyhteistyökumppaneilla on mahdollisuus kehittää uusia liiketoimintamalleja tähän teknologiaan perustuen. Samankaltainen tekstiilinlajittelukoneisto voidaan toteuttaa useissa Euroopan maissa.

Avainsanat: Kierrätystekstiilit, infrapunatekstiilit, kuidut, kierrätys, spektroskopia

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LIST OF ABBREVIATION

CO2	carbon dioxide
IR	Infrared
NIR	Near-infrared
LCA	Life cycle assessment
MJ	Mega joule
GWP	Global warming potential
HTP	Human toxicity potential
AP	Acidification potential
EP	Eutrophication potential
ATP	Aquatic toxicity potential
NRADP	Non-renewable biotic resources depletion potential
ODP	ozone depletion potential
POCP	Photochemical oxidant creation potential
PET	Polyethylene terephthalate
NMR	Nuclear magnetic resonance
NMMO	N-Methyl morphine N-oxide
TPA	Terephtalic acid
EG	Ethylene glycol
NM	Nanometre
FTIR	Fourier Transform infrared

FIR	Far-infrared spectroscopy
MIR	Mid-infrared
VIS	Visible spectrum
TA	Terephtalic acid

1 INTRODUCTION

In the global scale increasing environmental issues have changed the consumer way of thinking, increasing negative effects of textile production on the environment has changed operative activities of governments and industries. Textile recycling is a part of the REISKA project to investigate suitability and potential of various types of recycled fibres for commercial purposes as well as developing business opportunities in textile recycling in Finland. This thesis is written in the light of the REISKA subproject of recycling textiles and its flow to identify polyester fibre, which is one of the exhausted stream textile, sorting and efficient way to recycle and separate fibre. The main purpose of the REISKA project is to increase the business opportunities for SMEs in the Päijät Häme region. The new legislation aims to reduce textile waste to landfilling. In addition, the development plan is drawn up which can be used to create new business opportunities for textiles and fibres industry, to achieve the objective of the project, other developed system for textiles recycling industry need to be investigate. In order to find out the possible implementation in the Päijät Häme region and Finnish textile recycling industry as a whole. The aim of the thesis is to investigate the Dutch textile automated fibre and clothes sorting technology and, business opportunities in the new methods of sorting textile.

1.1 Motivation

Today, consumption and production of textile have increased because of growth in global population and high standard of living. The main reason for increasing textile production is relatively because of the fashion industry where consumers have new clothing demand for every season. Thus, fashion industry of clothing increase the amount of new clothes which also increases textile waste, consumption of virgin fibres and natural resources (Zamani, 2014, 1).

According to the previous research from Lahti University of Applied Sciences results, the average annual textile waste in Finland per capita is about 17 Kg and the amount of textile waste is increasing. Therefore, new waste legislation aims to reduce total amount of waste which is going to landfill, the new legislation states that from January 2016 textile waste no longer can be landfilled in Finland. Thus, textile waste is one of the substantial waste which is associated with climate effects. According to findings on the production of new textiles is required high amount of water, energy and chemicals, 15 kg of CO_2 per kilo textile is generated (Peterson 2015). Textiles and clothing are produced in the developing countries where environmental and labour legislations are not practiced properly. Importantly, recycling textiles fibres and automated sorting is more economical and environmental friendly compare to virgin fibres for the clothing industry.

The collecting and sorting of textiles which are performed manually today are mainly sorted by humans, in the result manually textile sorting is not efficient and accurate, it is rather time consuming. Although, the pioneer and leader of textile collecting, sorting and recycling are doing textiles sorting manually like German textile recycling company SOEX which is a leader in textiles recycling while using up-to-date technology for textile recycling. Technology which enables automated textile's sorting and recycling need to implement in the textile's industry to make this industry more sustainable. Therefore, an efficient sorting and recycling chain has to meet the new requirements of the textile recycling industry. Existing methods of sorting and recycling textiles are low on the commercial scale. To compete challenges in the textile automated sorting and textile recycling technology must be developed on commercial scale and provide knowledge in particular area.

To meet fashion and clothing industry needs, textiles are composed of composite materials. Therefore, the fabrics are produced from fibre blends, in other words, more than one fibres are spun at the same time together. Accessories which are used in the textile are such as buttons, zippers and other little accessories made of plastics or rubber. To separate textiles efficiently automated clothe sorting technology is required.

Automated textile sorting is one of the biggest challenge at the moment on a large commercial scale, in order to meet these challenges, various applications of infrared and other technologies are needed to make textile's industry more sustainable and environmental friendly. To meet present and future challenges in textiles recycling industry innovation has developed in one of the European country which is the Netherlands. Emerged technology is based on Infrared spectroscopy technology, the main purpose of infrared optical spectroscopy technology is to make textile sorting process fully automated. This technology will bring revolution in the industry of recycling textiles. The Netherlands is the pioneer of inventing and introducing infrared based technology for sorting clothes.

1.2 Objective

The main objective of this thesis is to investigate state of the-art-technology which is based on infrared optical spectroscopy technology for automated textile sorting. Based upon the preliminary research the questions to be answered are:

1. How IR technology can make textile clothing more sustainable?
    a. What is IR Technology and how this technology works?
    b. How Infrared technology works in textile recycling technology?
    c. What is the best IR Technology available at the moment in textile industry?
2. The main manufacturer of near-infrared technology for automated textile sorting?
3. How IR technology can be developed and implement in Finnish textile recycling industry?

- Structure of the Thesis

The author investigates Infrared spectroscopy technology in textile recycling industry, to investigate Infrared spectroscopy technology Dutch state-of-the-art-technology is chosen, specially automated cloth sorting machine is the main target of this research. In addition, on the base of findings are there any possibilities to implement same kind of technology in Finland?

2 TEXTILE FIBRES PRODUCTION AND ENVIRONMENTAL IMPACTS

To implement sustainable techniques of textiles fibres from production to recycling process of textiles, it is important to investigate the structure of fibres, processing methods and its impacts on sustainability. To achieve the objective of textiles fibres, Life cycle assessment of textiles fibre is important to analyse and the durability of textiles product Life cycle. Technology that enables chemicals and textile recycling process impacts on the environment is essential to take into account. In this chapter, the author will investigate the types of fibres, their production process and chemical & physical properties, the effects of production of fibres on sustainability will be investigated as well.

2.1 Textile fibres

There are two types of textile fibres which are natural fibres or man-made fibres. In the natural fibres, there are three categories which can be categorized according to their chemical classes. (Peterson, 2015, 8)

Natural plant fibres categories are:

- Cellulosic, the main source of cellulosic fibre is various parts of plant
- Protein fibres, protein fibres are got from wool, hairs and silk
- Mineral fibres, asbestos is the main source of mineral fibres

Man-made fibres have three classifications

- Regenerated fibres, Regenerated fibres are made from natural organic polymers
- Synthetic fibres, Synthetic fibres are made from non-renewable resources.
- Inorganic fibres, glass and ceramics are the main source of inorganic fibres

Natural plant fibres are considered more environmentally friendly than synthetic fibres. There are many reasons such as, the growth of plants absorb CO_2 from the atmosphere, natural fibres plant consume less energy compared to synthetic fibres and polymers, the end life cycle of natural fibres is biodegradable. There are many components of natural fibres but the main components of natural fibre plant is cellulose that can be taken through the enzymatic microorganism. (S Rana et al. 2014, 2). Man-made fibres are made by extruding dissolved polymer over the small preambles of a spinneret. In the process of filament yarns, yarn comprise one infinitely long fibre, where the fibres are cut into shorter pieces and spun together. (Peterson, 2015)

Developing countries play significant role to produce cotton, production movement and process of cotton into finished garments. Therefore, in the last two years 2012-2013, in the developing countries the total production and finished good from cotton was (97%) and local mills usage was (96%) compare to total world cotton production was about (86%). In this context, developing countries such as India, Brazil, Turkey and China are the leading producers of cotton on global scale. (Rana, S. *et al*, 2014). However, the demand for cotton on global scale is increasing every year due to world population growth. To meet required demand for cotton fibres, a new sustainable approach to producing cotton is required. In the year 2014 demand for fibres was about 89.4 millions of tonnes (Lenzing 2015) Figure 1 shows the global fibres market for the year 2014.

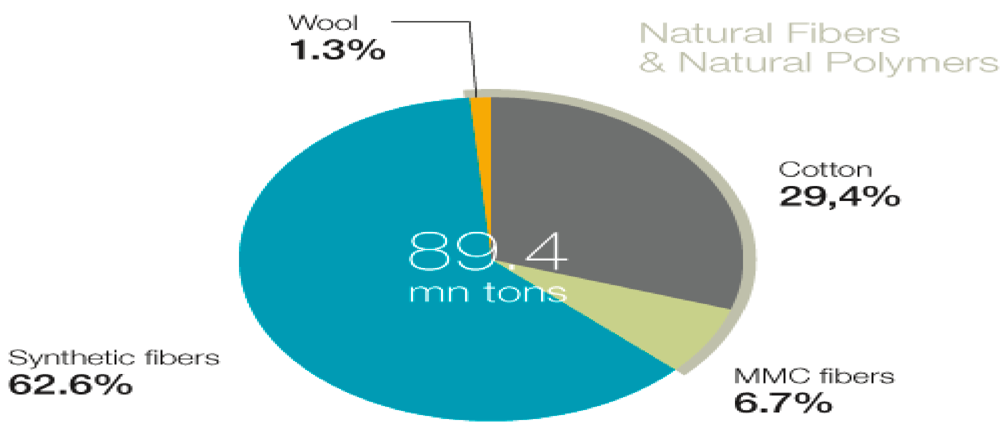

Figure 1: Global Fibre market 2014. (Lenzing, 2015)

2.2 Natural fibres

- Cotton Fibre

Cotton is a cellulosic fibre which is obtained from natural resources, cotton is one of favourite fibre for textiles and fashion industry. The total representation of cotton fibres in the textile industry is 38% and recently polyester took lead in the fibre consumption for clothing industry. The producer of the cotton countries about 90 in the world, most of the developing countries are producing it on large scale, in the developed countries United States of America, Australia are prominent. Most of the area on global scale it dedicated to cotton production which is about 2.4%. Cotton producing is expensive and sensitive yield where chemical, pesticides, fertilizers and expansion of irrigation and mechanical harvesting. (Blackburn, 2009. 33-34) Due to cotton production there are global ecological effects, it is estimated that 25% of global insecticide has increased with the comparison of 11% world's pesticides consumptions. There are other effects of cotton production, use of chemical, water consumption and fertilizers. Most pesticides and chemicals are not environmental friendly, which are involved to have negative impacts on human and environment directly and indirectly. (Blackburn, 2009, 34)

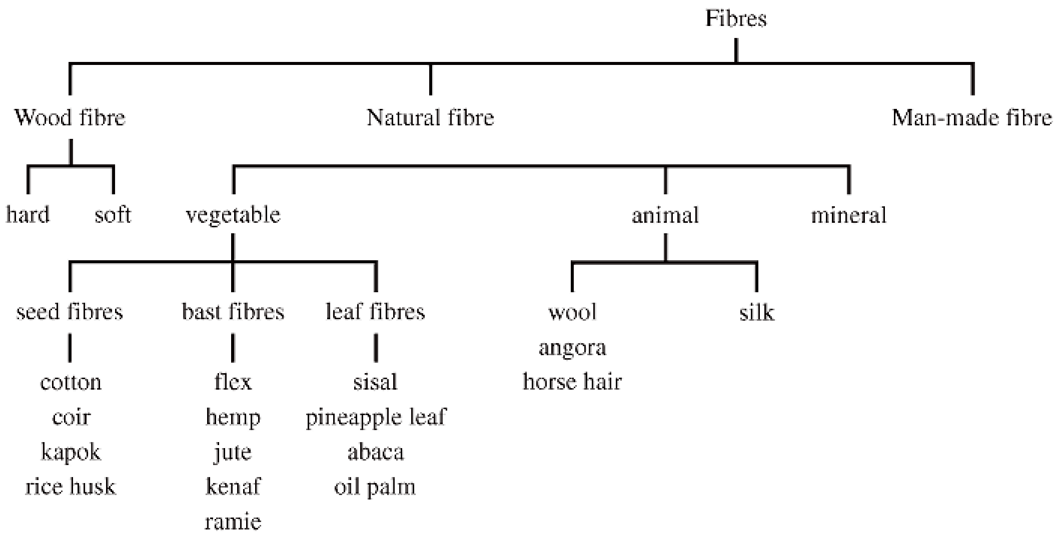

Figure 2: Fibre classification (Natural and wood fibre Reinforcement in polymers, Bledkzi et *al*, 2002)

- Jute fibres

Jute fibre is produced from the stem of the jute plant. This plant has a long length and is soft with a shiny appearance. According to “S. Rana” Jute fibre is cheap in production and is classified in the term of golden fibre because of its golden colour. Jute fibre is composed of cellulose, lignin and pectin. (Rana, *et al*, 2014, 7)

- Polyester

The production process of polyester is mainly chemicals used are terephtalic acid and dimethyl terephthalate that are made of ethylene glycol. The main method involved in the manufacturing of polyester is purifying terephtalic acid (TA) and it is based on bromide-controlled oxidation. In the purest petroleum products are not only used as feedstock but also other fossil fuels are used to produce energy to transform the fibre. To produce 1 kilo of polyester 109 MJ energy is required. Water consumption in the production of polyester is lower than compare to the production of cotton, Ploiesti can be processed with various techniques the most common technique consuming small amount of water through routes from one route to another route. (Fletcher 2014, 17)

- Linen Fibre

Linen fibre is made of flax plants, the main origin of the production is from the Mediterranean region of Europe. Linen fibres contain about 70% cellulose, in the linen fibre there is anti-allergic characteristics. Fibres made of linen are very flexible and textiles made of linen fibres are the best use of in the summer because of the passing of air through the linen fabric. In this fabric, it is easy to breathe compare to other fabrics. In the process of making linen fibres there are few chances to safe linen fibres against the alkalis, chlorite and hypochlorite washing agents do not affect the linen fibres in the cold conditions. Moreover, linen fibre has good resistance against natural solvents. Therefore, the entire process of making linen fibre is easy and sustainable (Rana *et al*, 2014, 8)

- Hemp Fibres

Hemp fibres are composed of stalk and hemp plants grow rapidly, Hemp have low-impact system of agriculture, in addition hemp helps vibrant land for other yields; hemp improves the structure of the soil through strong roots which control the erosion. The climate for hemp production required cool climate. The time for hemp to be completed is between four months and height is about one to four meters and crop six tonnes per hector. (Fletcher, 2014, 34)

Cellulosic or cellulose fibres are composed of natural sources like linen, cotton, hemp and jute. These fibres have been investigated in brief introduction and their chemical properties.

- Protein Fibres

The protein fibres are composed of natural animal source through compression of a-amino acid from restating polyimide with several substituents on a-carbon atoms. In addition, protein fibres have resiliency, elasticity and moderate in fibre structure, excellent moisture absorbency and transport characteristics are the main benefits of Protein fibres. (Natural protein fibres, 2015)

- Wool

Wool is a natural protein fibre composed of highly crumpled hair fibre derived from sheep. In the wool fibre pesticides are used in the cultivation of wool fibre although quantities of pesticide is lower than cotton fiber. According to Fletcher 2014 Sheep's are treated either with injectable insecticides, a pour- on-preparation or dipped in a pesticide bath to control parasite infection, which if left untreated can have serious welfare implications for the flock. The proper handling and process of pesticides in the cultivation of wool can have low negative environmental impacts. However, poor pesticides handling system can impact on human health and ecosystem both on the form and in subsequent downstream processing. (Fletcher, 2014, 14)

Table 1: Textiles fibre types (Fletcher, 2014)

Natural fibres		Manufactured fibres	
Plant	Animal	From natural polymers (vegetable and animal)	From synthetic polymers
Cotton	Wool	Regenerated cellulosic fibres	Polycondensate fibre
Flax	Silk	*Viscose*	*Polyester*
Hemp	Cashmere	*Modal*	*Nylon*
Jute	Mohair	*Lyocell*	Polymer fibre
Ramie		Alginate fibres	*Acrylic*
Sisal		*Acetate*	*Polypropylene*
Banana		*Triacetate*	*PVC*
Pineapple		Elastodiene (rubber)	Triexta fibre
		Regenerated protein fibre	*PTT (hybrid of*
		Casein	*synthetic and*
		Soya bean	*natural polymers)*
		Biodegradable polyester fibre	
		Poly (lactic acid) (PLA)	

- Cashmore (Kashmiri)

Cashmere wool is made from goat and it also called Pashmina, from the warm and soft under layer of hair. Cashmore comprise straighter and coaster which is good for the protection of hair. The process is natural to get natural fibres during the moulting season. At the time animal naturally shed their hairs. Mostly goats mould during the spring time. Cashmore hairs are extremely warm to protect goats from cold in the mountain temperature. The fibres which are obtained from cashmore are easy to adapt and simple process to change them in the yarn. From cashmore light to heavy warm clothes are made. The characteristics of cashmore fibre are lightweight, soft and similar like wool, finer in quality and warm enough compare to other fibres. (Natural Protein Hairs/Fur, 2015)

- Alpaca fibre

Alpaca is known as alpaca wool or alpaca, the alpaca fibre is like other natural fibres which contains various qualities. The good quality of the alpaca fiber consist of Royal and baby alpaca because of its softness and smooth silk. Alpaca fibre is considered as a fiber for luxurious textiles products which are widely used in the United States of America and other developed countries. The production of alpaca is natural shade from off-white through fawn also brown to jet black. The properties of alpaca fibre are lighter than wool and warm for the weight. There is natural water resistant, the strength of alpaca fibre is better than wool fibre due to its thickness and microns. Textiles and clothe made form alpaca are fines in quality and ideal warm clothes for outdoor outfit. (Alpaca fibre, 2015) a natural fibre which is derived from Alpaca, the fibre can be heavy or lightweight mainly depends on the spun and how much the process have been made, durability, softness and nature of Alpaca fibre is similar to sheep wool. Alpaca is naturally watered-repellent and is difficult to ignite, naturally fibres composed of Alpaca are long and generally stronger than other fibres. They are used in the expensive luxury textiles and apparels. (Protein fibres, 2015)

- Silk

Silk the natural protein fibre which is made from chrysalis of silkworms. Most production of silk produced through systematic way. Cultivation of silk contain many varieties that is involved feeding worms a carefully and diet is controlled to produce good quality of silks. For silk production there are other applications which are used in the process like, fertilizers, pesticides. At the time of selecting pesticides it should be keep in mind that worms are extremely sensitive to agro-chemicals. (Fletcher, 2014, 15)

- Angora

Angora rabbit region is unknown, however, the hairs are very soft and fine and the use of angora fibre is in high quality knitwear. Angora hairs basically consist of two types French and other alternate of angora is rarely used chashmore. French hair are longer and contain guard hairs, similarly, other types of angora hair is fewer sharp and recycled to create a softer yarn. At the moment china is the world leader with 90% of producing Angora rabbit hair, Angora fibre is produced by Angora rabbit and Angora goat, while Chile is the second producer of Angora rabbit hair. (Angora, 2015)

2.3 Mineral fibres

Mineral fibres are composed of synthetic materials. In the mineral fibres, asbestos is the main source of mineral fibres which is derived from silicate minerals, and asbestos are obtained from various kind of rocks. In natural mineral fibres, there is silicate of magnesium and calcium which contain aluminium and other natural minerals. The composition asbestos is based on iron which is obtained from silicate which is good for acid proof, flame proof and rust proof. (Classification of fibres, 2013, 24)

- Glass wool

Glass wool fiber is based on fine, long, and inorganic bonded by high temperature binder. The diameter of glass wool fibre is about 6-7 micron. The distribution is made in such methods that, the composition of good thermal insulation and acoustic insulation properties can be made while using millions of tiny pockets of air product. The main use of glass wool fibre is insulation materials, such as walls, celling and external heat and cold protection for construction purposes. (Mag Hard Insulators, Glass wool, 2012)

- Asbestos fibre

Asbestos fibre is composed of six naturally occurring stringy minerals. There are six sub classifications of Asbestos fibre which are, Chrysotile, Crocidolite, Amosite, Anthophylite, Termite, and Actionlike. Asbestos fibres are microscopic in nature and enormously dynamic in fire resistance, in addition asbestos fibres have resistance against chemical reaction of itemization. (Mesothelioma, what is Asbestos, 2013).

- Production of natural fibres

In the sub chapter of this thesis, the author will investigate the production process of natural fibres, even though natural fibre fabrication method is eco-friendly but further technological developments are required to achieve sustainable approach.

The natural fibres can be defined as bio-based fibres, vegetables fibres and animal origin, cellulosic fibre is one of them. (Environmental benefits of natural fibber's production and use 2015. 1).

- Cotton fibre production

Cotton is one of the most natural consuming fibres, the method of processing cotton fibre is complex and have negative effects on the environment. The cotton cultivation process is long and natural resources are required on large scale such as water energy, fertilizers, pesticides and agriculture instruments. New research has found that 15,000 litters of water is required to produce cotton for one pair of jeans. (Rana et *al*, 2014, 9)

- Jute fibre production

Jute is the bast fibre which is highly produced, although, in the textile industry jute has never been used that much compere to its production. Jute fibre production is simple to cultivate, seeds scattered by the farmers in the soil, four months are required to ready jute fibres. However, before processing and making fibres from jute plants, it is very important to dry them and keep jute plants in the sun in the figure of bundles convert to dryness. Jute fibres have various approaches to process jute plants: mechanical process, chemical process, chemical retting, steam and water microbial retting etc. The required temperature to process jute fibre is 70-100 F and humidity (70-80%). From degradation studies, it was found that the total weight of jute fibre is decreased by 50%. And 30% in bending strength and 90% in impact strength related to pure Biopol. (Bledkzi, *et al*, 2002, 6)

- Linen fibre production

The process for flax plant (or linen) production is about three months from the day when flax plants are planted in the soil, this process takes a place from cultivation till ready-to-use linen fibre. In the production agriculture chemicals mostly fertilizers are used to promote strong growth and herbicides to control weeds. For flax growth little quantity of fertilizers can be used as long as water is available. For good quality of linen climate should be very humid but slight and wide irrigation is not normally required. The environmental effects related to water consumption, pollution and soil salinization are avoided. (Fletcher 2014, 16)

- Hemp fibre production process

The production process of hemp fibre is comparatively limited and the structure remain embryonic. At the moment, hemp fibre is subsidy in the European Union for non-food agriculture and a considerable initiative has been under way for further development in the Europe. (Bledkzi et *al*, 2002, 5) Process of hemp fibre is considered annually which grows from seeds in different varieties. To produce hemp fibre, land should be well drained enough quantity of nitrogen and nonacidic, land with high yield of corn is more suitable for hemp production. Mild climate, humid atmosphere and annual 64-76 cm rainfall is required for the best hemp fibre production, required time for hemp crop to get ready is about 70-90 days. After harvesting there are four to six weeks required to get dry hemp which depend on the weather. (Industrial Hemp, Gisela, 1997)

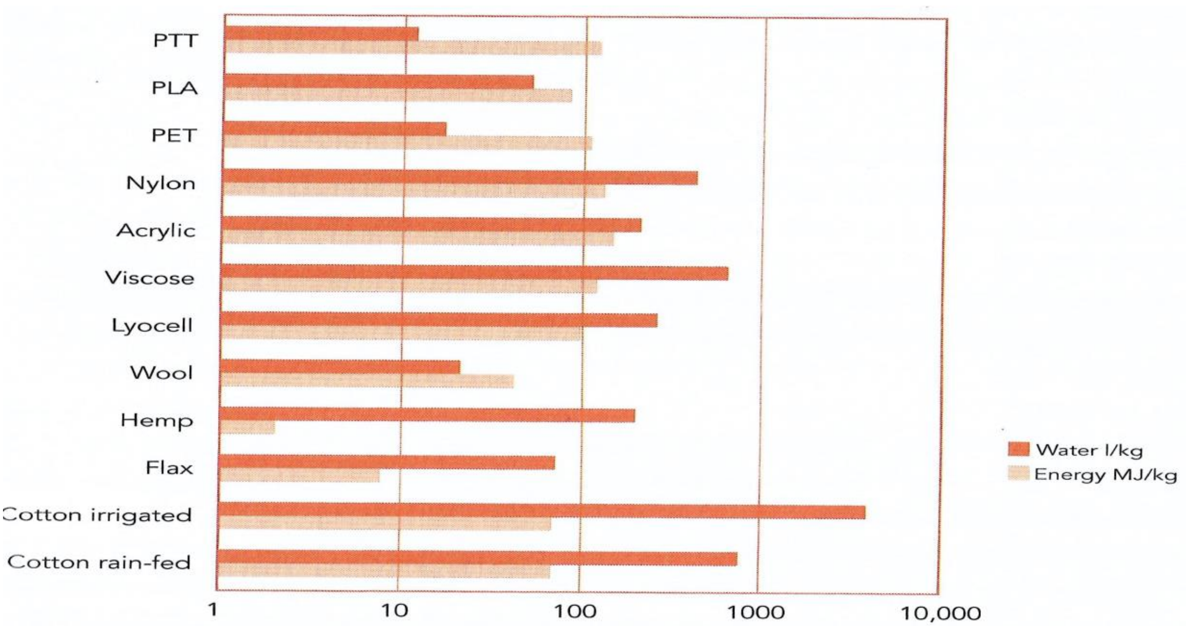

Figure 3: Energy and water consumption in the production of selected fibres types on the long scale. (Fletcher, 2014)

2.4 Sustainable natural fibre

Natural fibres are to be considered a sustainable and renewable, biodegradable and environmental friendly. Mostly natural fibres material is exerted from the environment, fibre derived from plant, animal, natural sources. Naturally fibres can be made or processed with hand or simple tools. In the natural fibres simple industrial processing is made for example cotton and polyester, natural fibres are considered environment friendly and long life cycle of fibres in different textiles and durable. The important factors are more important to consider as sustainable fibres, these factors are soil, land, energy, air and quality. (Stokke *et al*, 2014, 2)

- Sustainable cotton fibre production

The greatest sustainability challenges for cotton cultivation lie in to lessen pesticides, fertilizers and water usage for cultivation and guiding formers about sustainability. Sustainable way to cultivate cotton is not to use synthetic pesticides, fertilizers and growth regulators may address these issues. Organic cotton or producing cotton in sustainable way is to avoid using fertilizers and synthetic pesticides, as natural methods are used to control weeds and diseases and, pests control. However, these techniques has been used in the recent time to make cotton production sustainable. The results from these techniques brought positive change on environment. In the recent times, the usage of pesticides and chemical in the cotton cultivation has decreased to 8.5% to grow various crops. (Fletcher, 2014, 26-27)

Cotton can tolerate heat and cotton field do not need a large quantity of water. In many regions of the world, natural resources are used for cotton cultivation, for example water is taken from the natural resources. Cotton cultivation has tiny impact on the environment. With the help of modern technologies, the total land for cotton cultivation has decreased about 50% compare to last forty years. The dust emission from cotton fibre has been decreased quickly. In the result total emission has been decreased and energy requirements for cotton production are decreased through biofuel from cotton seeds. (Rana *et al*, 2014, 10-11)

- Jute fibre production’s impacts on sustainability

The production of jute fibre is based upon annually renewable resources. Compare to trees jute fibre has more potential to make paper production since in the jute fibre there is high biological efficiency compare to trees. Using jute in the paper production instead of tress will also save forests and reduce cutting down trees.

Jute can grow naturally without fertilizers and chemicals, jute production fibres do not need chemicals and pesticides. The waste generated from jute is transferred into organic matter and enriches the soil with nutrients.

There are many organics and gases generated at the time of jute fiber production. These chemicals and gases are acetone, ethyl, alcohol, butyl, methane, carbon dioxide and hydrogen sulphide. However, in the resultant CO_2 and other emissions are the main reasons of global warming and climate change. Jute planting can be useful in other factors which prevent many diseases and improve health conditions. (Rana *et al*, 2014, 12)

- Sustainable linen fibre production

The customary process of degumming from linen fibre from the stalk involve water renting, placing a small bundles in water tanks. Running water or water in the tanks are used for separation of fibres from wood core. The best technique for separating fibres from wood core is to plants are left in the ground to decompose woods to right condition of heat and moisture, this method is called dew renting. In the linen process shallower ploughing method energy is not required as compare to other fibres, however, the linen process which cause less soil erosion of soil. (Fletcher, 2014, 16)

- Hemp production's impacts on sustainability

For the production of hemp, there is no need to use artificial fertilizers and pesticides are required. Weeds and disease of hemp are the main issue for organic cultivating hemp formers. Hemp leaves many of sheds leafs before harvesting, nutrients which are left form Hemp are useful for next crop. Enrichment of soils occurs due to hemp plants as they are thrown out of their leaves to soils throughout the whole growing seasons and hereby produce a mature compost. Hemp plants are good to maintain the structure of soils because of its long roots in the soil. There are many reasons to cultivate hemp on commercial since there are many impacts of hemp production in the soil. Hemp is the more sustainable fiber, and it's ideal for sustainable textile's industry. (Waayer *at el*, 2015)

- Natural fibre production’s impacts on the environment

Eight types of environmental impacts have been identified through Life Cycle Assessment. Therefore, study shows that processing of natural fibres has negative impacts on the environment in different ways, which are given here shortly. Global warming potential (GWP), human toxicity potential (HTP), acidification potential (AP), eutrophication potential (EP), aquatic toxicity potential (ATP), non-renewable biotic resource depletion potential (NRADP) ozone depletion potential (ODP) and photochemical oxidant creation potential (POCP). These are the main environmental impacts which are affecting the environment in different ways. (Rana *et al*, 13-14)

Figure 23: Environmental Comparison of Fibre type. (CLEAN by design, 2015)

- Composite fibre

According to Stokke *et al*, “A composite is combination of at least two materials, each of which maintains its identity in the combination. Combinations of synthetic polymers with advanced engineering fibres, or plant fibre as amalgamation of the natural polymers, cellulose, hemicelluloses provide example of sophisticated composite,” The classification of composites can be approached in various ways, one simplest way of classification is “natural," or “synthetic," composites. (Stokke *et al*., 2014, 7)

- Regenerated cellulosic fibres

Most of the fibres are made of natural resources plant, minerals and animals, are called natural fibers. In the fibres chemicals are used cannot be classified in natural fibre, for example, rayon fibres are made of reconstituted chemically from the cellulose plant, But in general they are not considers as a “Natural fibers” due to degree of chemical is required to form them. (Stokke *at el*, 2014, 2)
Regenerated fibres are also called man-made fibres, these fibres have been created using various kind of synthetic and building blocks delivered by the nature. These regenerated fibres are somehow called natural fibres but chemical wet process has been used to change the composition of regenerated fibres, for example cotton and

natural protein are the examples. However, there are two main types of regenerated fibres, regenerated fibres from cellulose and other one is made from natural protein. (Ecofibres, 2015)

- Bamboo viscose fibres

Viscose bamboo fibre is a cellulosic fibre is made from natural polymers, the polymers are dissolved chemically and extruded to continue filament. The main source for viscose is planting soft woods like beech, even though bamboo cellulose tree got popularity. However, the sources for making cellulose fibre is considered carbon natural because of less CO_2, beech tress absorb the same amount of carbon dioxide and it give out to harvesting, there is a good circle for carbon dioxide. However, the production process of viscose fibre have implications on environment. (Fletcher, 2014, 18).

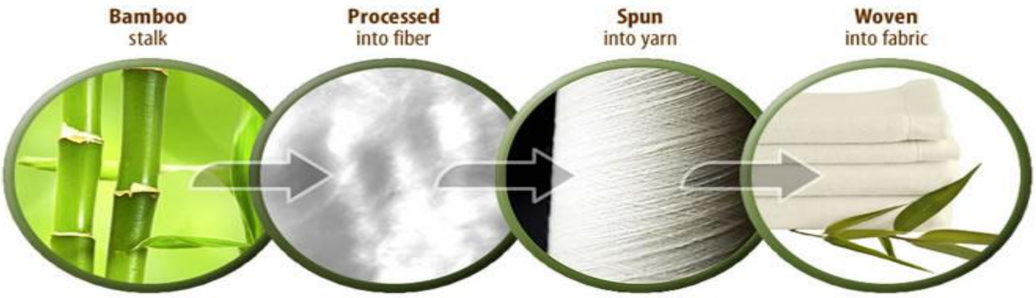

Figure 4: Process of Bamboo fibre production (Roadmap to sustainable textiles and clothing industry, 2014)

- Cellulose acetate fibre

Cellulose acetate fibre is a man-made fibre, the main origin of acetate fibre is natural, and due to chemical process acetate falls in the category. In the textile industry various types of fabrics are made from acetate fibre with its own material or mixed with other artificial materials, fibres, yarn or synthetic. Through thermo-elasticity pleat skirts are made from acetate fibre. Furthermore, the fibre made of acetate is lither than cotton and nearly equal to wool fibre. (Acetate filament yarn from Swicofil, 2015)

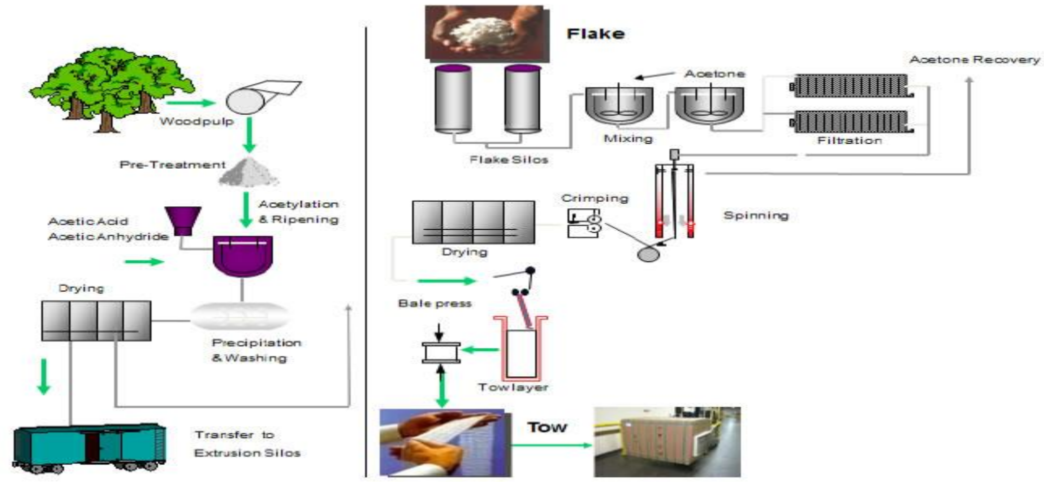

Figure 5: The process of acetate fibre production (Roadmap of textiles and clothing industry, 2014)

- Lyocell fibre

Lyocell is a cellulosic fibre, it is derived from wood pulp and normally eucalyptus. The claim is made that lyocell fibre is an environmental friendly and for the production process renewable resources are used as its raw materials. The wood pulp is dissolved in a solution of a solvent and after this process anime oxide is spun into fibres and solvent is exerted as a fibre thorough washing process. (Fletcher, 2014, 38)

- Sea cell fibre

Sea cell fibre is in its third generation which is regenerated from natural cellulose fibre which is environmental friendly production method. This fibre is produced using modern technological Lyocell techniques. Processing method of sea cell is integrated in the nature of essentially closed nature cycle process. Sea cell fibre contains vitamins, minerals and trace elements. There is positive impact of sea cell fibre, which is good for skincare effects (SmartFibre AG, 2015).

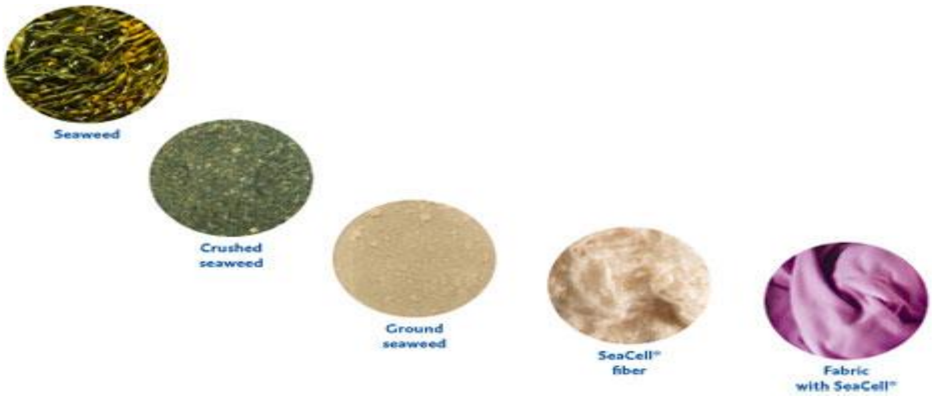

Figure 6: Lyocell Fibre processing technique. (SmartFibre AG, 2015)

2.5 Man-made fibre production impact on sustainability

The research is conducted to investigate the effects of regenerated cellulose fibres on the environment. Life Cycle Assessment tool was used to analyse environmental impacts of these regenerated fibres. In the regenerated fibres studies, it was found that Lenzing AG is producing 20% of the total world cellulosic fibre. All steps starting from the extraction of raw materials, fuels, production methods and until delivery of staple fibre to the factory gate were reflected on. (Rana *et al*, 2014, 263).

- Sustainability impacts

The findings repeatedly show confusion over the sustainability impacts of cultivating and mining textiles materials. In the findings, it has been proven that synthetic fibres are bad to environment, while natural fibres are good. These conclusions have been made on the basis of complex sets of factors like raw materials, renewable resources, biodegradability and various stereotypes association which have made the conclusions. Undoubtedly, there is no dispute that making synthetic fibres have bad impacts on the environment and on the people. On the other hand, natural fibres also have negative submental impacts on environment. Thus, there are different challenges for different fibre production. The process of recording and assessing impacts are involved directly and indirectly for the purpose of making fibre. The natural resources which are consumed for fibre production (energy, water, chemical and land) and waste are produced from this process. There are some great impacts on product life cycle phase. (Fletcher, 2014, 11)

- For fibre production large amount of water and energy is required.
- Carbon dioxide to air, water and soils is increasing to produce synthetic and cellulosic fibre.
- Negative impacts of fibre productions are linked
- Use of energy and non-renewable resources for synthetics.

- Sustainability parameters

Sustainable approach to produce regenerated cellulose fibres, the use of water, land and energy are considered properly. On the other hand, there are other factors considered like potential for global warming, ozone layer depletion, abiotic depletion, human toxicity, freshwater, aquatic Eco toxicity, acidification and photochemical oxidant formation. Therefore, from research it is found that regenerated cellulose fibres are not environmental friendly. Thus, to achieve the target sustainable and technological approach is required (Rana *et al*. A roadmap to sustainable textiles and clothing 2014, 263). Table shows the detail of used fibre for LCA.

Table 3: Table shows the geographic scope of regenerated cellulose, cotton and PP fibres used in LCA

Regenerated Cellulose Fiber					
Fibers used	Trade Name (Fiber type)	Wood	Pulp	Fiber plant	Process energy
Viscose (Asia)	Lenzing viscose	Eucalyptus	Market pulp	Asia	Local electricity, coal, gas, oil
Viscose (Austria)	Lenzing viscose	European Beech	Integrated pulp and fiber production in Austria		Biomass, recovered energy from MSWI
Modal	Modal (modal)				
Tencel	Tencel (Lyocell)	Eucalyptus and Beech	Mixed Lenzing pulp and market pulp	Austria	70 % gas, 30 % biomass
Tencel (2012)	Tencel (Lyocell)				100 % recovered energy from MSWI

Commodity Fibers			
Fibers used	Type	Geographic scope	Data source
Cotton	Natural fiber	US and CN	Literature data
PET	Polyester	Western Europe	
PP	Polyolefin	Western Europe	

- Relooping fashion Initiative

The relooping fashion has been started to spun worn-out fibres into new thread. There was a problem to re-producing old cotton clothes into new clothes, but relooping fashion initiative has made is possible. Relooping fashion initiative improves the quality of post-consumers textiles and maintain the quality of re-produced fibres. The new technology bring options for virtually huge amount of cellulose- based fibres without adding harmful chemicals or other materials, which prevent environmental issues on global scale. This new development has been made using a cellulose dissolution technique developed by Finnish technical research centre. (The Relooping fashion initiative, VTT Finish Technical Research Centre, 2015)

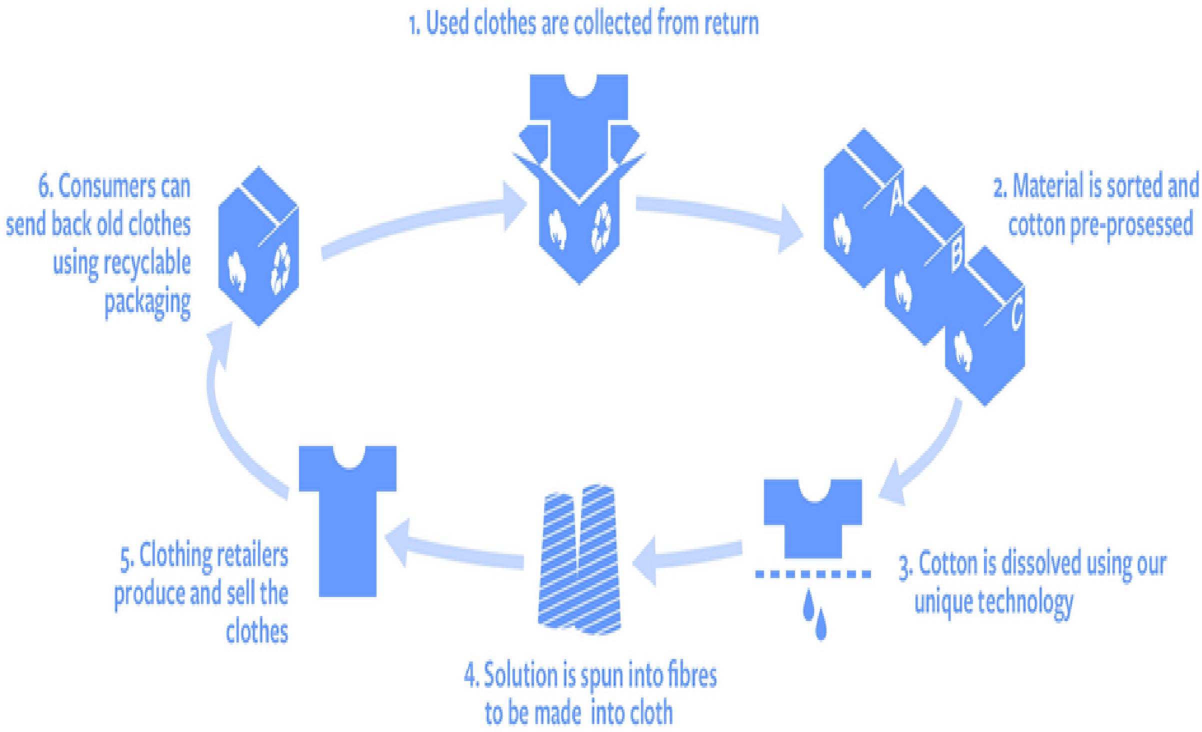

Figure 7: The Relooping fashion. (What is the relooping fashion initiative, 2015)

Conclusion

Study shows that generating new fibres from raw materials are not environmental friendly. Moreover, the composition of natural or regenerated fibres are required natural resources to complete their production process of raw material to the factory gate and from factory gate to consumers. Developments in technology and textile waste management systems are required to preserve natural resources for future use. In the developing world people are already faced shortage of energy, clean drinking water and other natural resources like natural gas due to global warming and rapidly changing climate.

3 TEXTILE RECYCLING AND ENVIRONMENTAL IMPACTS

3.1 Present situation of recycling of textiles

An investigation was conducted by J. Lu and co-workers about the current status of textile recycling the reuse of textiles (Peterson, 2015, 18). The outcome of the survey provided most significant results in the textile industry where fibre waste in China 12% in Japan 13%, and 15% of the fibre waste in the United States of America is reused or recycled. While in the Europe, Germany is the leading country with 66% of the estimated textile fibre revenue is both recycled and reused in different methods. In Germany federal organization for secondary and primary raw materials are recovered and recycled in different ways. (Peterson, 2015. 18).

There are mainly two paths for textile recycling summarized. The two main areas of textile recycling which are the focus in this thesis, sorting of textiles by the Infrared application and chemical recycling, identification of chemicals by infrared spectroscopy.

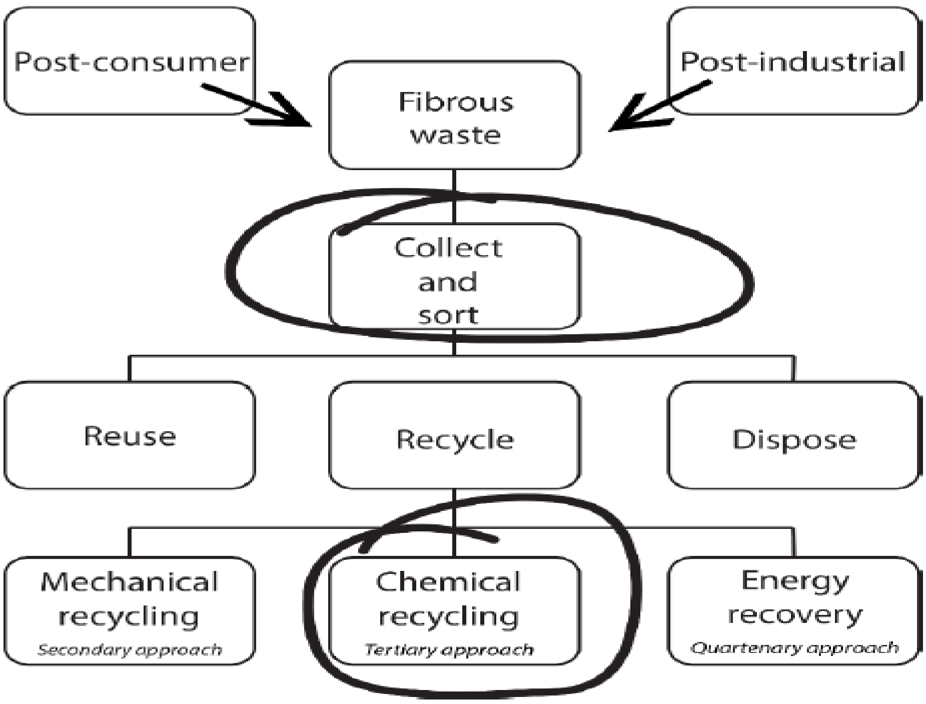

Figure 8: Path for textiles recycling (Peterson, 2015)

Currently textile sorting is done manually in the developing and developed countries which seems there is room for further development in sorting textiles. For textiles to be recycled technical challenges need to be overcome, there are two mains challnegs for recycleing textiles degradation and blending of fibres. Degradation process make fibre and polymers chain length shorter, further mechanical recycling make polymers and fibre even more short, shorter length of fiber and polymer means lower strength and quality. These factors make major problem for efficient closed-loop recycling. (Peters *et al*, 2014, 189) Therefore, the technology based elucidations proposed for industrialising the method, such as tagging all manufactured clothes with radio frequency identification technology which specific composition. However, there is another technology which is based on the infrared or near infrared technology. NIR (Near infrared) seems the best solution for sorting and indentifying textile based on chemical composition or the blended fibres. (Peterson.2015, 19) The focus of chemical recycling technology is mainly based on cotton and polyesters which enable dissulation of old textiles to replace virgin materials. Assessment suggests that chemical recycling of cotton and polyester fibres provide significant environmental benefits over energy recovery. (Peters et al, 2014, 189)

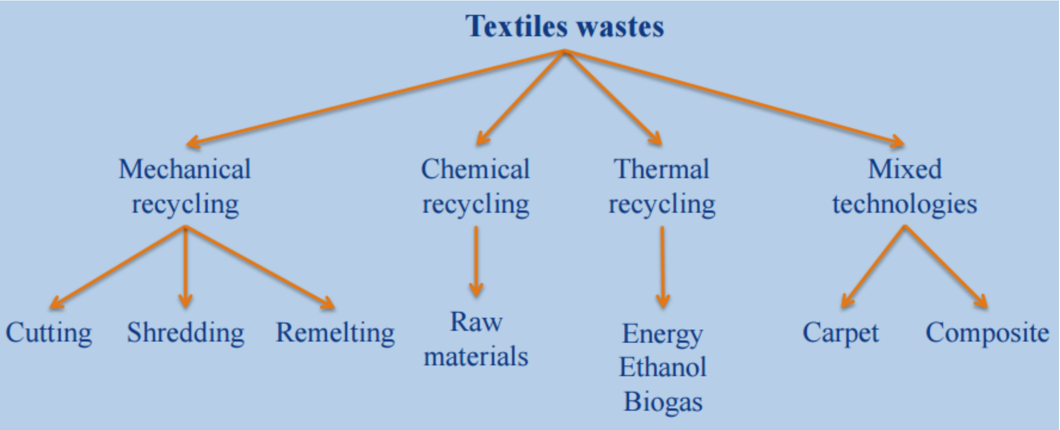

Figure 9: Textiles waste recycling (Textiles recycling technologies, 2013)

Textile waste recycling technologies can be divided into four categories with various techniques based on the raw material and product made of ending process. process (Peterson 2015, 19). Industrial waste is the primary method to create new products equal to new value waste. Currently all textiles which are sold as made from recycled textile fibres, today they are produceded from industrial waste according to primary approach. On the other hand, secondary approach is mechanical processing of post consumer products. Thermoplastic polymers which is possible for mechanical recycling is used melted and re-extruded, for example polyester and nylon. To achieve a value of polymer equal to the raw waste material the polluted waste should be on the low scale. Recycled PET bottles approach is the best way to obtain while using fleece clothing system. (Peterson, 2015, 19) To process cotton and wool which can be combined and spun into new thread the mechanical recycling method is used. There is another approach which is based on chemical recycling which is called tertiary approach, in this method polymer are fully or partly depolymerized. (Peterson, 2015. 19) To adequate understanding and control of textiles materials, the focus is on the complete understanding of textiles fibres, on the molecular level (molecule scale), on the macromolecular (polymer scale) and morphological level (fibre scale) these techniques are better for restoring post-consumer textiles fibres. (Greg peters *et al*, 2014, 190)

3.2 Challenges in Textile Recycling based on chemicals

Textiles are most complex materials. There are many textiles materials which are composed of fibre blends to achieve required properties. For example, when textiles are coloured, this method makes fibre stronger to attach dyes. However, textiles can be preserved with specific chemicals to make properties such as fire proofing or water resistance. Chemical intense and residues from methods might be contained in the textile for industrial method of textiles. In the textile’s industry the usage of thread for seam is often a different type fibre compare to fabric in general and there are alternative materials yet to present. (Peterson 2015, 20)

For closed loop system blended fibre is another issue for chemical recycling, the problem is not merely based on the use of yarn types individual yarn has different types cellulosic or synthetic blends. These problems rise here since sorting is impossible based on the fibres types which are used in the garments. There is no commercial online analytical techniques for identification of the fibre content in the garment. Secondly, mechanical textiles recycling is complex due to mixture of fibre after tearing for example polyester is stronger than polyurethane. Chemical dissolution separation are difficult because it is difficult to tune one type of chemical since there are mixed fibres. (Greg peters *et al*, 2014, 189)

In the process phase textile fibres are degraded. Mechanical textile recycling is the process which make degradation of textiles comes during use of laundering. On the other hand, fibres is the another process of degrading. Little changes in the structure of the fibres and physical aging can make huge changes in the shape of non-crystalline polymer chains that decreases the molecular mobility of polymer. Molecular mobility of the polymer makes inelastic material with big tendencies to permanently break down stress on the molecular polymers. On the other hand changes in chemical aging causes to include thermal degradation, hydrolysis and many other oxidation reactions. Moreover, it is proved that decreasing net weight in molecular can make problem in tensile strength and edacity of the fibre. It can also cause in chemical reactivity. (Peterson, 2015, 19)

To make high value textiles from textile waste, it is recommended that the modern sorting automated technology should be used to sort textiles from blend textiles. The quality of degraded textile to be upgraded to high quality fibres. However, specific methods to have adopted to accomplish recycling textiles materials into high level fibres. (Peterson, 2015, 20)

3.2.1 Challenges in textiles recycling

The biggest challenge in the textile recycling is to find the best possible way to reduce burden on natural resources and find societal effective way to keep sustainability. Textile industry has made significant environmental impacts. To make natural fibres are the indicators of increasing global warming with the use of pesticides, chemicals, herbicides, energy and water in the textile industry. To lessen the impact of these factors sustainable textiles and reuse of textiles and other materials are the demand of the present time. (Porse, 2013, 7)

Recycling is the concept of reducing waste and reuse of old materials and make raw materials for new products. Recycling is the ecosystem, where waste from different materials become raw material for another product. (Fletcher, 2014)

To meet societal and present needs continues improvements are required for increasing the value of recycled textiles. However, this is not only based on the chemical and mechanical processing but also required to manage recycling of fibres and textiles. On the commercial scale of decomposable and compostable materials incoming the waste stream. (Textiles exchange, 2012)

Mechanical fibre recycling and chemical fibre recycling is the key to differentiate fibres based on their composition, downcycling process is eliminated by chemical processing. However, down cycling is able to produce almost equal quality of fibres compare to virgin fibres. In the mechanical recycling of natural fibres, there are various types of fibres are recycled like, cotton and wool are the most accessible recycling technology for post-consumer materials. The life cycle of recycled fibres through mechanical recycling techniques is not the efficient as recycled fibres from this method have other life cycle compared to virgin natural fibers. (Recycling clothes in the fashion industry, the Guardian, 2015) In the mechanical textiles waste recycling method is based on shedering, output of recycled waste have lower quality, the material is used in the carpet and stuffing. However, new technological methods are required to improve the quality of textiles recycling. (Peters et al, 2014, 190)

Figure10: Mechanical Recycling textile waste recycling process. (Textile recycling, 2013)

Chemical recycling is used for only polyesters and nylon fibers, however, the life cycle of these fibres are shorter than regenerated fibres or virgin fiber. New technologies are being developed for chemical separation of fibers with the cooperation of various companies like. (Recycling clothes in the fashion industry, the Guardian, 2015)

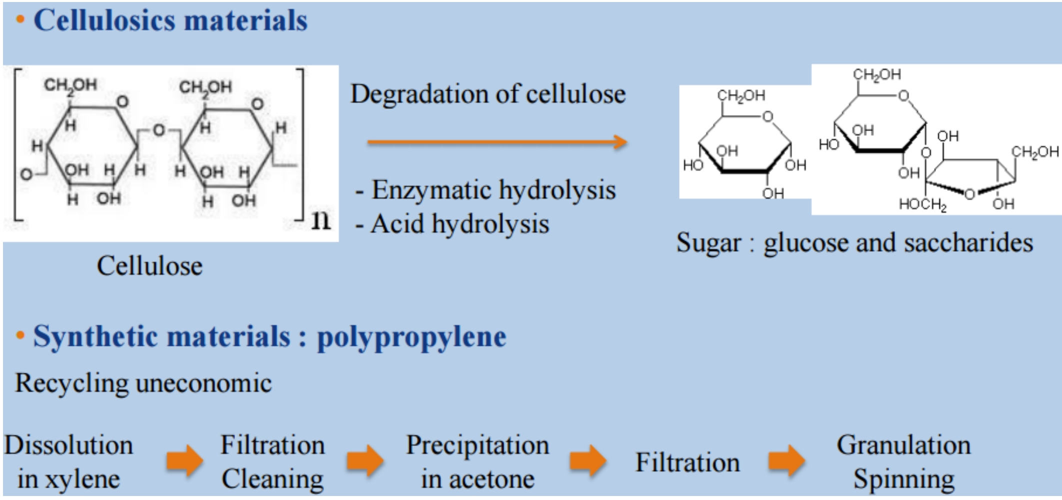

Figure11: Chemical textiles recycling cellulosic materials. (Textiles recycling technologies, 2013)

3.3 Textile Analysis

The development process of online, offline and characterization of textiles analysis is required to develop this technology.

At the moment textile sorting is done manually for recycling textiles. Therefore, required target can be achieved by implementing modern technologies like online and offline methods and right kind of characterization of materials. Analytical techniques and other applications for textiles sorting based on fibres and colours. New technique online or offline will bring huge change in the quality of sorting textile. To achieve these goals there are three rules that must be followed which are. (Textiles circular program, 2015)

- High throughput
- Ability to distinguish between fibres
- Ability to analyse fibres

Spectroscopic applications are the best techniques for automated sorting purposes. This is the process of interaction of electromagnetic radiation with materials, process which is certain energetic transitions which can be detected and it is used for sample identification. On the other hand, there are many spectroscopic techniques which provides rapid recognition based on sample analysis.

It is important to analyse textile materials which can be executed off-line. Over classification of textiles, it is essential to elucidate molecular structure of fibres to measure the fibre content in fibre composite.

Infrared (IR) spectroscopy, Raman spectroscopy, solid state nuclear magnetic resonance and solid- state NMR are the best solution for further investigation. The main purpose of the spectral library of common textile fibres is to detect their ability to use the quality of fibre analysis.

In the processing to identify moisture and monitor reaction vibrational spectroscopy techniques are used, the techniques are Near-infrared (NIR), IR and Raman have been widely used in the textiles handling techniques. However, in the solid-state NMR spectroscopy is not applicable to analyse on-line techniques because of the setup of the experiment. On the other hand of this, solid-state NMR spectroscopy is very interesting for textile recycling purposes due to its ability molecular structures. However, these techniques are made to build a textile spectral library that can be used as a reference for further analytical techniques. (Textiles4textiles, 2012)

3.4 Process of separating textile based on chemicals

At the moment, different fibres have been used in the textile industry for different purposes, but most used fibre is Polyester-cotton blend, which is very common to use in the services area such as curtains and bed sheets, etc. (Peterson 2015. 22). Therefore, high demand in Polyester-cotton blend provide new way of thinking in the process of separating fibres in pure fraction to make recycling process more accurate. The process of separating fibres can be made in different methods, in this case systematic method is used to separate fibres in which is given in the figure.

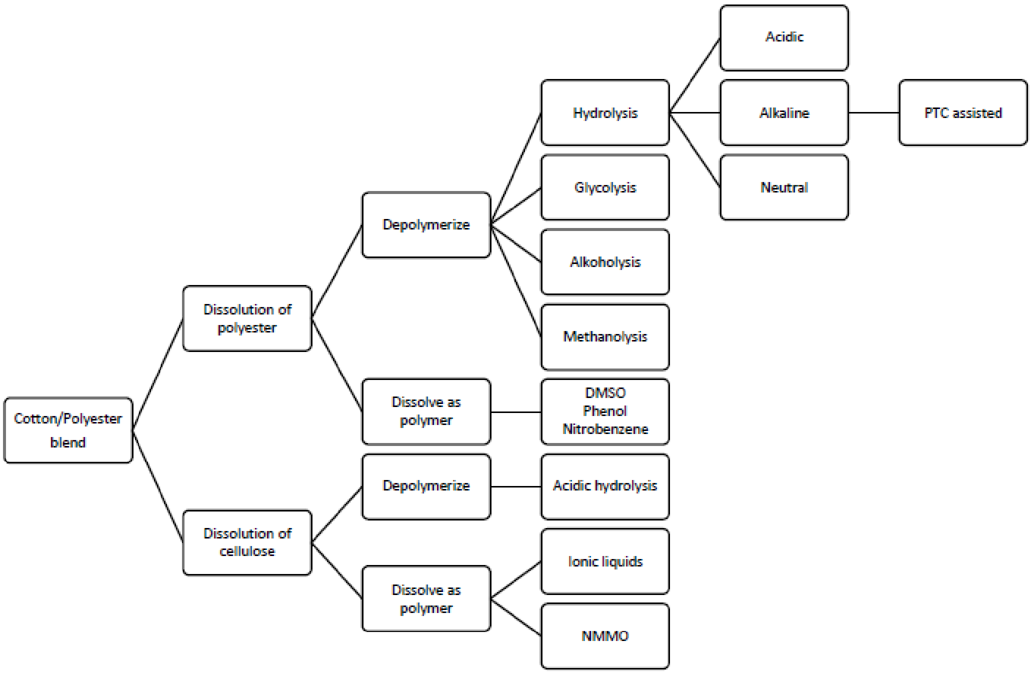

Figure 12: Polyester-cotton separation systematic methods (Peterson, 2015)

Recently the subject of devolving cellulose fibre into separate Pollycotton blends in order to separate the pollycotton blends. Cellulose is hard to dissolve, hence expensive and specific solvents such as n-methyl morphine n-oxide (NMMO) or ionic liquids are used. Therefore, cellulose fibres can be treated in the chain to regenerate them into viscose or in Lyocell fibre (Peterson, 2015. 21).

In polyester there is low solubility in common organic solvents, therefore, in the process of separating fibres in this method more solvents are required to make cellulose fibre in sustainable approach. However, processed fibres can be re-spun in the process to clean impurities such as dyestuff, on the other hand of this there is another method to purified cellulose with the help of re-polymerized. There is another method which can be sued in the process of hydrolysis of PET under the acidic alkaline. However, in the process of separating Polyester cotton for the purpose of recycling, neither acidic nor neutral conditions are used, the reason behind the process is acidic environment which would depolymerize the cotton fibre nor neutral conditions are required for this process under the high temperature and high pressure. In the end of this process the fibre will be degraded in the final condition. On the other hand hydrolysis is suitable since cotton has high resistance to alkaline so conditions is good under moderate temperature. (Peterson, 2015. 23).

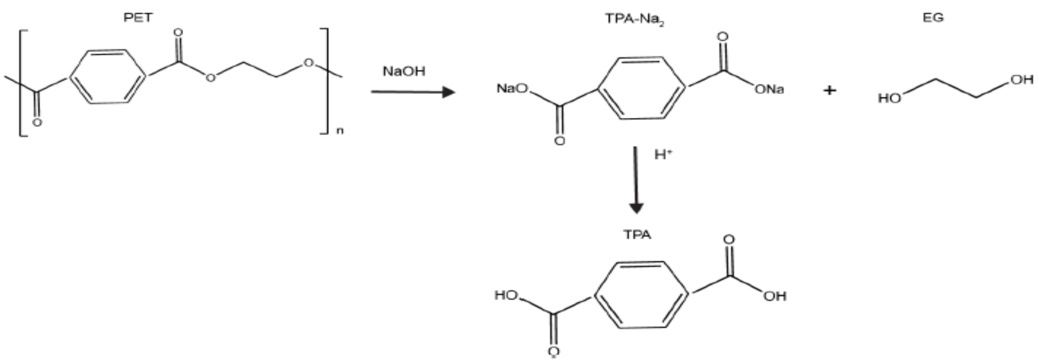

Figure 13: Alkaline hydrolysis of PET (Peterson, 2015)

3.4.1 Products made from separated fibres

There are main three products which are made from alkaline hydrolysis of polyester cotton textiles, the products are terephtalic acid (TPA), Ethylene glycol (EG) and cotton. TPA has solid form, which is based on precipitate whereas EG is the representation of organic component in the aqueous phase needed to be gained from recovered materials.

Cotton can be categorised into man-made cellulose fibre with the help of dissolution, the DP of cotton is ideal in the crystalline from 400-600nm. There are effects on the cotton fibre structure due to dissolution mechanism in the different stage of thermodynamically sustainable process. (Peterson, 2015, 23).

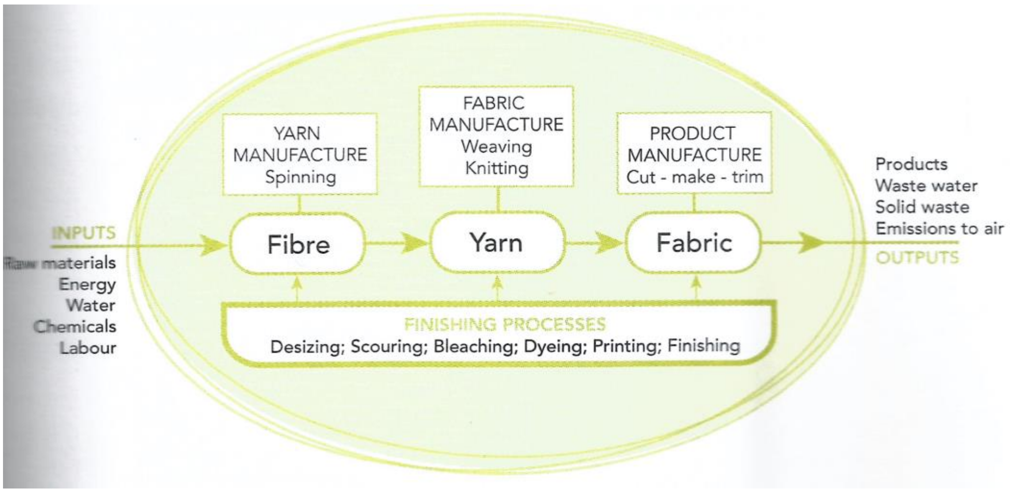

Figure 14: Process of textile recycling materials, (Fletcher, 2014)

3.4.2 Environmental impacts of textile recycling

One of the today's most pressing environmental issue is the increase in materials use and waste generation. Finding new methods to process textile's waste and utilise it in sustainable way is the first priority of the EU. Textile recycling industry has achieved remarkable success to reduce greenhouse emissions with different recycling methods. Today one of the main issue is increasing CO_2 rapidly on a global scale. However, when solid and textiles wastes are buried in landfills, they release CO_2 as buried waste are decompose. Similarly, at the end of other side of the clothing life cycle spectrum, the production of new textiles fibres and manufacturing of new clothes have negative impacts of environment.

4 INFRARED SPECTROSCOPY TECHNOLOGY

In this chapter the author will examine infrared spectroscopy and its applications in textile recycling industry. In this chapter different approaches of infrared, near-infrared, vibrational infrared spectroscopy and Raman spectroscopy as well as Near-infrared will be discussed. However, the later part of this chapter introduction to IR and its various applications in textiles and fibres will be examined under the different techniques. The focus will be on the basic of IR technology and its applications in textile industry based on spectral techniques.

In the spectroscopy, spectral analysis is very accurate and sensitive to identify the qualitative and quantitative analysis of fibres. These techniques have been used widely in textile industry for analysis of textile fibres. (Jilin 2015. 1).

4.1 Introduction

Infrared spectroscopy is one of the main analytical technique which is widely used in the field of science and technology. With the help of this technology is possible to access any kind of sample virtually. Moreover, the applications of infrared technology has been used in many fields of the science for sampling techniques like fibres, gases, films, pastes, powder, liquids and solutions. These materials can be easily analysed. (Stuart. 2004. 6)

In every compound there are covalent bonds weather organic or inorganic, to absorb various frequencies of bonds electromagnetic radiation in the infrared region of electromagnetic spectrum. The region of wavelength is longer than visible light, the range of spectrometer is around 400nm-800nm (Nanometres). The wavelength is shorter compare to those microwaves which are longer than 1 mm (millimetre). For chemical purposes, vibrational portion of the infrared region is used. (Pavia *et al*, 2009, 15)

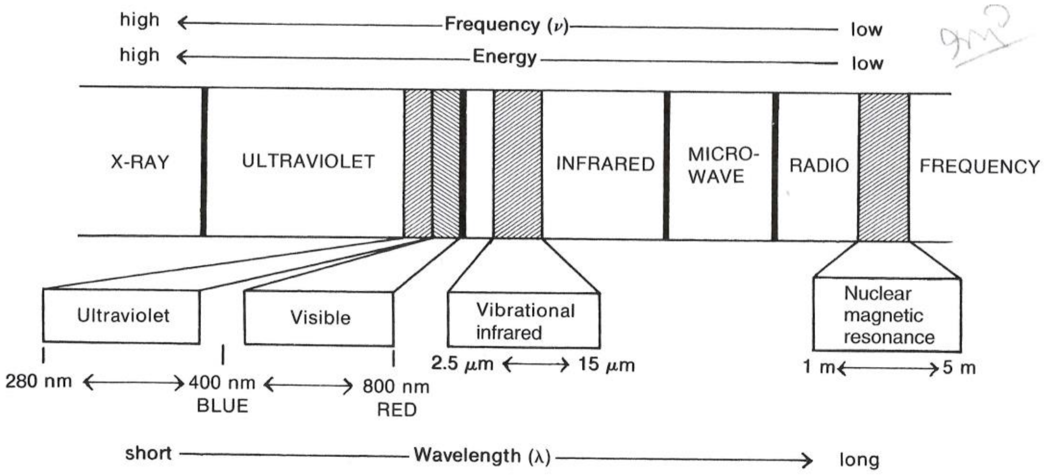

Figure 15: A portion of the electromagnetic spectrum showing the relationship of the vibrational infrared to other type of radiation. (Pavia *et al*, 2009, 15)

4.2 Infrared spectroscopy technology operational principles

The main working principles of infrared spectroscopy are based on the vibrations of atoms of a molecule. The spectrum of infrared is normally obtained passing through the infrared radiations during the processing of sampling. When object is passed through the infrared radiation, the friction of incident radiation is observed at the particular level of energy. (Stuart, 2004, 7)

Table 4: Type of energy transition in each region of the electromagnetic spectrum. (Pavia *at el*, 2009, 16)

Region of Spectrum	Energy Transitions
X-rays	Bond breaking
Ultraviolet/visible	Electronic
Infrared	Vibrational
Microwave	Rotational
Radiofrequencies	Nuclear spin (nuclear magnetic resonance) Electronic spin (electron spin resonance)

As other types of energy absorption, molecules are excited to higher energy state when they absorb radiation, absorbing radiation process is similar like other absorption process, a quantised process, and a molecule absorb only selected frequencies of infrared radiation. In the absorption process, the frequencies of infrared radiation which match the vibrational frequencies of the molecule in

Question are absorbed, and the energy absorbed serves to increase the amplitude of vibrational motions of bonds in molecules. (Pavia *et al*, 2009, 16)

4.3 Experimental methods of Infrared spectroscopy technology

In this sub chapter, the author will investigate the experimental methods of IR technology, the main methods of experiment will be take into account based on sampling.

Since every type of bond has a different natural frequency of vibration, there are two same kinds of bonds have different compounds have different environments, two molecules cannot have the same structures but it is possible to have the same kind of infrared absorption pattern, thus infrared can be used for different molecules to absorb. (Pavia et al, 2009, 17)

4.3.1 Fourier-Transform infrared spectrometer

The main principle of FTIR is based on interference of radiation between two beams and after processing the radiation between two beams the signal is produced between two path lengths. Thus the frequency and distance between two beams is changed through the mathematical method of Fourier Transform. (Stuart, 2004, 23)

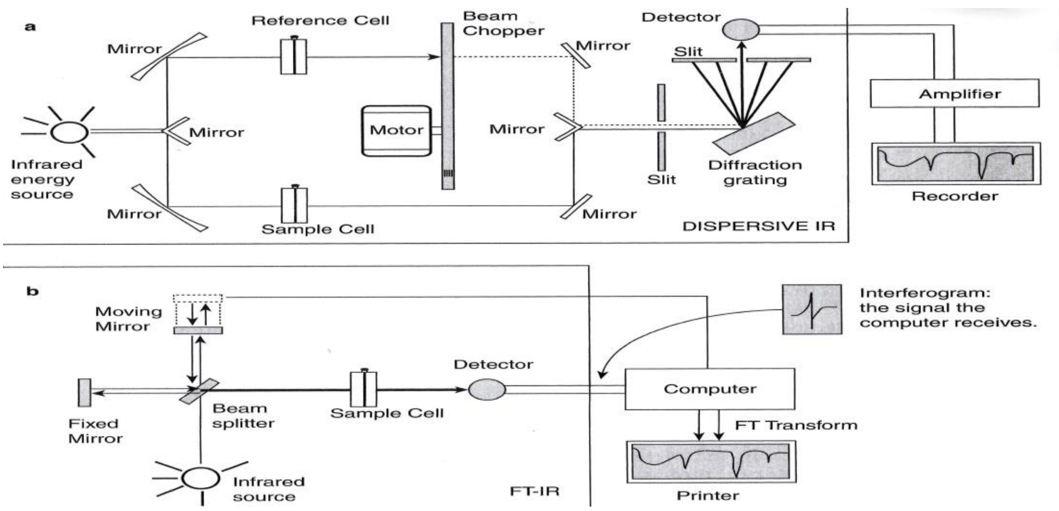

Figure 16: Schematic diagrams of (a) dispersive and (b) Fourier transform infrared spectrometers. (Pavia *at el*, 2009, 24)

In the Fourier-transform infrared spectroscopy there are other sub categories which consist of the following categories.

- Moving mirror
- Sources and detectors
- Fourier Transformation
- Signal averaging spectra

4.3.2 Reflectance methods

The main purpose of using reflectance methods are to analyse the samples which are difficult to analyse through conventional transmission. There are two categories of reflectance methods internal measurement of samples and external method of analysing reflectance is to use infrared beam (Stuart, 2004, 33).

- Attenuated Total Reflectance Spectroscopy

This technique is used to find total internal reflections based on spectroscopy, the beam is entering in the crystal radiation will reflect the indecency interface. The time of this process interface between the sample and crystal should be greater than the normal vibrant. It will reflect the two surfaces to observe total energy of sample. Thus, total reflectance of the material will change the material absorption and in the result, the radiation of attenuated radiation is measure by spectrometer (Stuart, 2004, 34).

- Specular Reflectance spectroscopy

The focus of the specular reflectance spectroscopy is to analyse in the external frequency radiation. In this process focus of radiation is to analyse sample radiation externally and internally to do so there are two methods which occurs specular and diffuse. External reflectance measure the radiation on the surface of sample. (Stuart, 2004, 35)

4.3.3 Infrared

Infrared or mid-infrared spectroscopy is the light wave which is used to analyse organic components in the spectrum, IR operates in the 4000-400 nm-1 frequency region. There are three intervals in Infrared spectral techniques, Near-IR, far-IR and mid IR which are used to identify materials from samples. Infrared techniques absorb the light of sample and spectrum plot the light of transmitted light versus wavelength. There are other techniques which are used in the spectrum. During the spectrum sample light matches in the natural vibrational frequencies, so in the resultant increasing energy increase the total amplitude of vibration. Hence, interaction with infrared based samples must be active and vibrational motion should be used in diploe moment. (Peterson, 2015. 25).

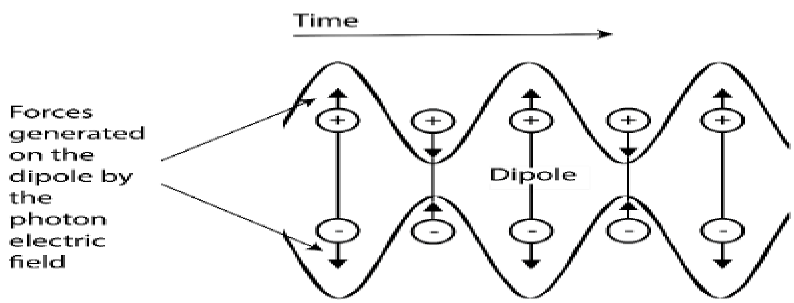

Figure 17: Frequency match with oscillation and dipole electric field generated by Photon. (Peterson, 2015, 26)

Infrared light is generated by the hot wire which is made from materials that emits the desired frequency. In the process of sampling for materials light wavelength is passed though monochromatic, the light is crossed through the sample which detect sample and decision is made accordingly (Peterson 2015. 26).

4.3.4 Raman spectroscopy

The fundamental function of Raman spectroscopy is based on scattering photons rather to absorb photons. Therefore, interaction between incoming radiation and oscillating dipoles is generated by the electromagnetic fields which is directly incoming radiation through the light. However, in the Raman process molecules are required to be in polarization states. Electrons can easily be distorted by the radiation as showed in the below figure (ANDOR 2015).

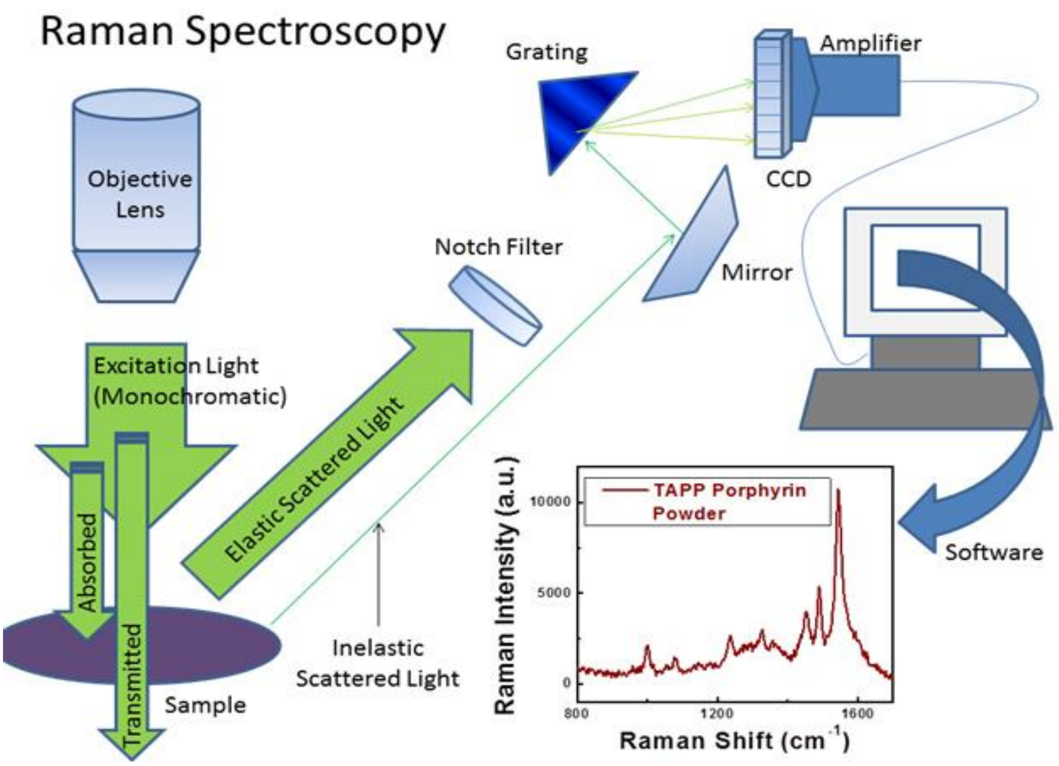

Figure 18: The radiation in the molecules (The Prashant Kamat Laboratory, 2015)

In the Raman process the most important thing is scattered light which is elasticity Rayleigh scattering. Therefore, in the Raman spectroscopy detecting material is based on the Raman scattering which means the intensity of this method is at least three times lower than the total magnitude and the intensity of Rayleigh scattering. In the Raman scattering there are two types of inelastic scattering modes which are Stokes and anti-stokes. The process of detecting molecules and the existence of molecules in the entire process is based on the molecules in the ground state and anti-stokes observe scattering Raman molecules are observed viberationally. Therefore to make thermal equilibrium distribution in the Boltzmann Stokes Raman scattering is used at the high level of intensity. (Princeton instruments, 2015, 1)

In the Raman spectroscopy technique laser light is used as a main source of the monochromatic light. The light is passed in the detector material through the main spectrometer where scattered light is used by entering a monochromatic which fix the light at specific wavelength. Therefore, rotating the same wave length indicate the light filtered out and not allowed to reach to analysing detector (Peterson 2015. 27).

4.3.5 Near-infrared spectroscopy

Near-infrared is a spectral technique which is used to identify the structure of materials and types of fibre, using spectroscopic methods near to the electromagnetic spectrum from 700 nm to 2500 nm. The NIR is based on vibration combination and over molecular nuance. Thus, to identify the solid samples under the NIR spectral technique. Therefore, it is not compulsory to make samples to identify the main fibres and materials in the structure of polymers (Analytical methods, NIR, 2015).

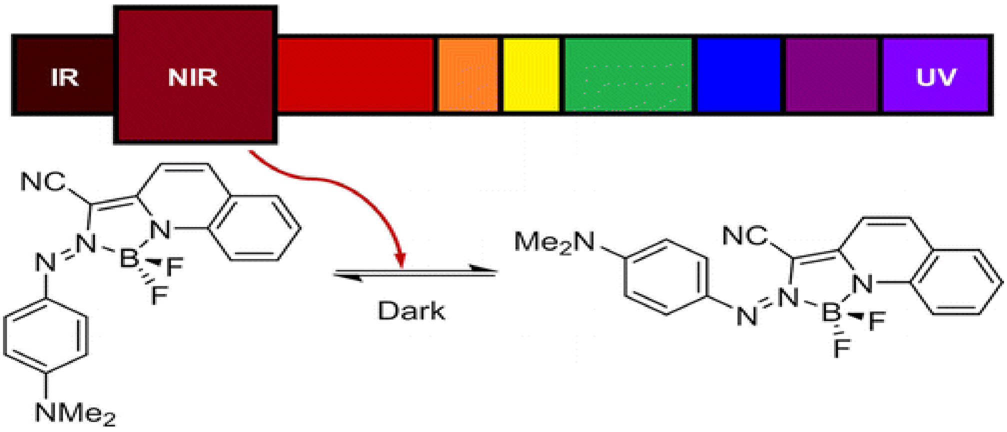

Figure 19: NIR light wavelength activated for absorption, (Chem station INT ED)

4.3.6 Far-infrared Spectroscopy

The range of Far-infrared spectroscopy 20-500nm, in this process entire molecule is involved with lower frequency in the form of bending and torsional motions for example lattice vibrations in crystals. The process of analysing molecular vibrations are sensitive to change the structure of molecules, which means to analyses these vibrations techniques in the Near-infrared region is difficult, the best possible option of detection molecules vibrations Far-infrared region is ideal. In the solid state materials differentiated is made while using Far-infrared bands of isomers and long chain fatty acid. (Derrick at el, 1999, 14).

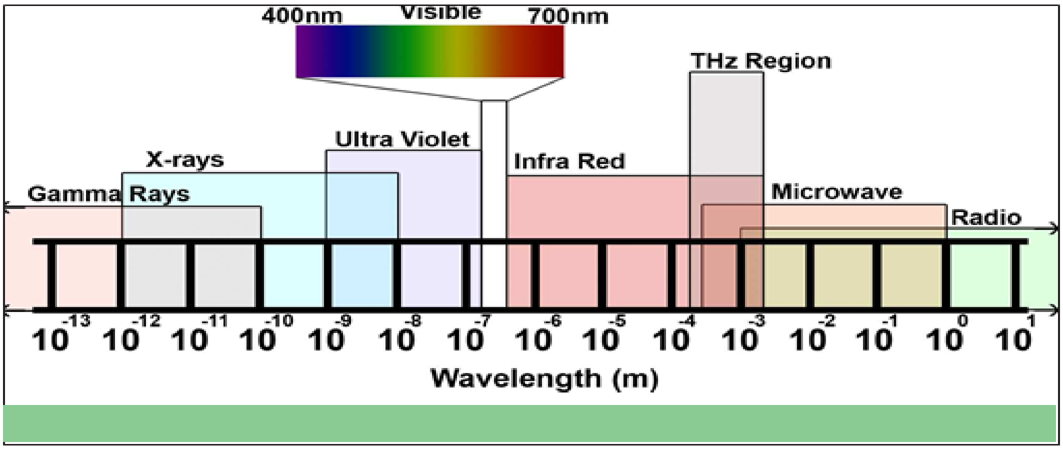

Figure 20: Far-infrared spectrum wavelength (Sciencetech, far-infrared spectroscopy, 2015)

4.3.7 Mid-infrared Spectroscopy

The mid-infrared spectrum is divided into four regions, the division and nature of the frequency is determined by the frequency which depends on the nature of the spectrum region. The spectral range of mid-infrared is about 4000-400nm, the regions in the mid-infrared spectroscopy are generalized as follows: X-H stretching region (4000-2500nm) and tripled bond region (2000-2500nm), double-bond region (2000-1500nm) and finally fingerprint region (1500-600nm). Moreover, the fundamental vibration region is O-H, C-H and N-H stretching. It has been found that the each band in the infrared spectrum can be given to specific bend of the molecule (Stuart, 2004, 46)

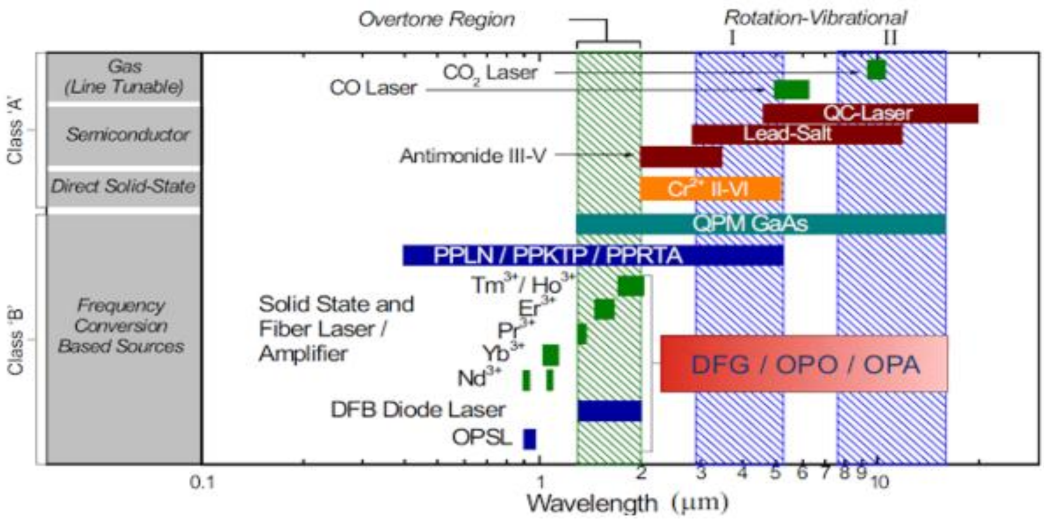

Figure 21: Laser source and its working range under Mid-IR

In the given figure is has been shown the vibrations of molecules and Mid-IR laser range. (LEI Wei's academic blogs, Mid-infrared spectroscopy, 2015)

- Process analytical technology

For sorting and process purpose analytical applications on IR are used, preferably NIR spectrometer is the best solution to identify the materials. IR sensors completely detect material with NIR spectrum, for each measurement 2D sensor-array is used. There is an application which is used in the sorting process is FT-NIR spectrometers. These -NIR spectrometers are working in a scanning mood. (Analytical Methods, 2015)

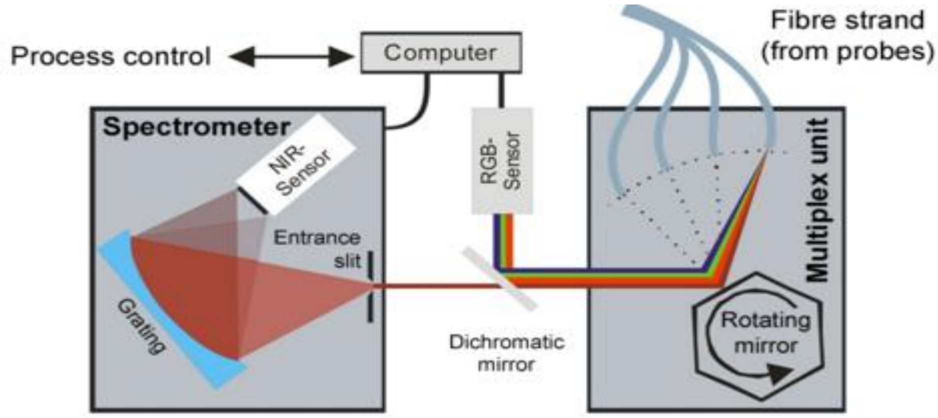

Figure 22: Principle of an NIR line spectrometer (Analytical Methods, 2015)

5 THE CIRCULAR TEXTILE RECYCLING AND SPECTROSCOPY TECHNOLOGY APPLICATIONS IN TEXTILES INDUSTRY

Infrared spectroscopy technology is an important technique in the textile industry. In modern era, various applications of infrared are used in textile industry to make textile industry more efficient, for example in the process of dying textiles IR technology is used. Moreover, infrared spectroscopy is used to separate blend textile fibres with Vibrational spectroscopy techniques. Infrared spectroscopy technological advancement is required to make textile recycling industry more efficient.

At the moment, textile recycling industry is fronting challenges to develop automated textile and clothe sorting techniques for recycling purposes. The current sorting system performed manually and is time consuming, which makes textiles and clothing recycling process deliberate. In the results it is expensive and in-efficient.

In this chapter Dutch textile waste management and textile recycling and sorting process is investigated. Moreover, innovation of automated clothe sorting and other applications of infrared spectroscopy will be investigated as well. The objective of this thesis cannot be completed until circular economy concepts are not presented here because Circular economy is directly and indirectly involved in this thesis project. The partners of FIBRESORT and Textiles4Textiles and various other textiles protects on the European level are involved.

5.1 Circular Economy

Current economy system is based on linear economy, in which natural resources are utilized to make new products. Most of the products which are made from these materials are not environmental friendly, which means products are disposed of after use. Therefore, from individuals and organizations perspective current economy system is not sustainable to meet future requirements for economies. Every individual and organization need to take step in circular economy. Furthermore, circular economy is a waste free economy, which means new products are in sustainable. (About circular economy, 2015)

Figure 23: Circular Economy. (The circular economy, 2015)

In the circular system all the resources are in closing resources loops, representing natural ecosystem in a way to make whole system sustainable. On the other hand of this, natural resources are utilized in sustainable way like, renewable energy system, social and ecological impacts of human activities. Therefore, six principles of circular economy are shown in the figure. (About circular economy 2015)

Figure 24: Environmental impacts of textile was management is shown in the recycling process. (Dutch textile waste management, 2015)

5.1.1 Dutch solid waste management

In the Netherlands recycling textiles is widely used option for municipal solid waste management. Recycling municipal solid waste already initiated in 1995. By the end of 2001, already 45% targets were achieved across the country. There are numerous fresh reforms introduced in the system to prevent landfill and reducing solid and textile wastes. At the same times landfill tax was introduced. Dutch municipal solid waste recycling target was already achieved efficiently by the end of 2009. Current Dutch municipal waste management plan is to increase the recycling of household waste 60% by the end of 2015. (Milios, Municipal Waste management in the Netherlands, 2013)

5.1.2 Textile waste management in the Netherlands

It is estimated that the annual household waste in the Netherlands is 210 tonnes, which is coming from only textiles and clothing industry. From 210 tonnes 75,000 tonnes is collected independently, which means rest of the waste is collected with residual waste. With optimization and separation techniques 65% of the textiles is recycled at the present time. Beside the household textile waste, each year 30 000 tonnes workwear and uniform are thrown away. (Closing the Textile recycling loop 2013, 1)

Textile collecting system in the Netherlands is based on modern transport infrastructure and efficient way to handle textile waste. In addition, textile waste is collected by four charities and recycling centres. Since there are business opportunities in the area of collecting used clothes, commercial companies like KICI, Reshare and Sam’s Kledingactie started to invest in this field. In the beginning of collecting used clothes, companies had full control over the market. At the moment, those charities and commercial companies are collaborating to make collecting used clothes and textiles in more efficient way. (Closing the Textile recycling loop 2013, 2)

5.1.3 Dutch textile recycling industry

Dutch textile recycling industry is one of the leading textile recycling in the world, VAR Frankenhuis is the heart of the Netherlands where old textile fibres are recycled efficiently. At the VAR plant, trimming form carpet industry, workwear and uniform, yarn and selvedge from spinning as well as materials from waving factories are recycled. Since, VAR processing plant for textile recycling is advanced in the textiles recycling, before, recycling textiles and clothes, all kind of unwanted objects like zips, buttons and bales are removed. Every year company produce tens of thousands of fibres for industrial use from used clothes as well as industrial trimming. The process unique and efficient not only in the Netherlands but also across the globe. (Closing the Textile recycling loop 2013, 3)

5.1.4 The Dutch green approach in textile waste management

Green approach strategy was introduced in winter 2012 to meet future challenges and technological advancement in textile recycling industry. The leading companies in the textile collecting and recycling sectors made a deal with Dutch government. The main objective of the deal to reduced textile in household residual waste half of it by the end of 2015. Currently in Dutch waste management system, textile waste stream is included in the second waste management plan. (Closing the Textile recycling loop 2013, 2)

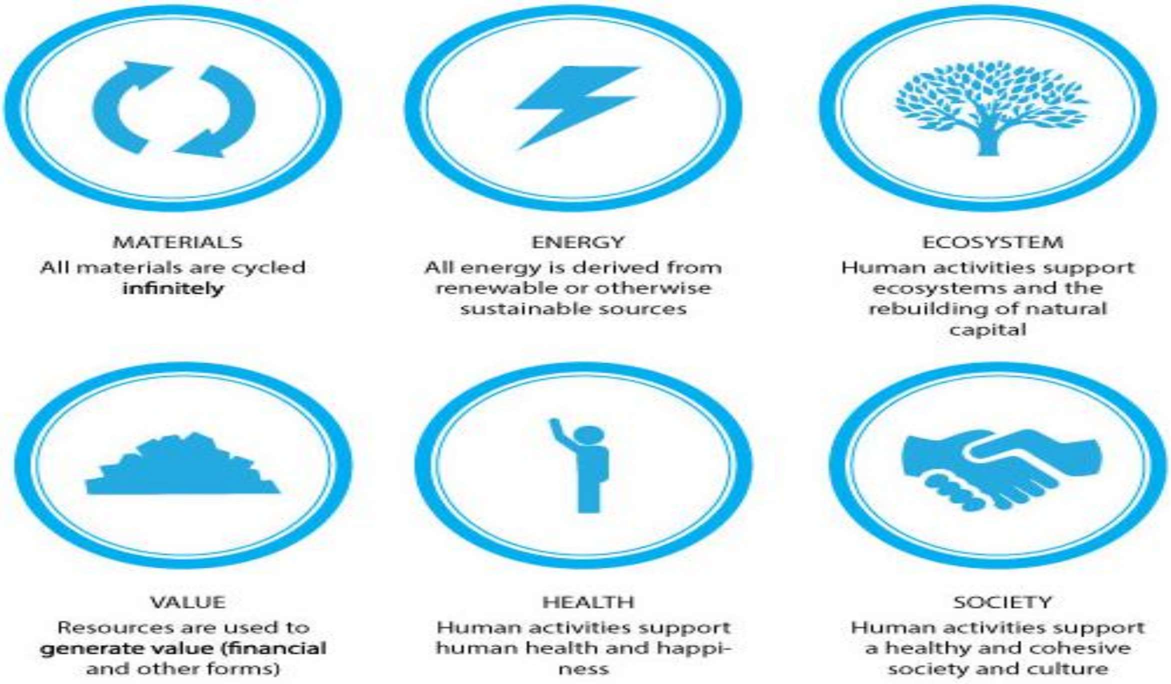

Figure 25: Closed loop, Circular economy (Circular economy, 2015)

5.2 The Circular textile program

The main objective of the circular textiles program is to establish a commercial and scalable program in the European Union under the closed loop system for post-consumer textile waste. The value chain in the industry of fashion and textile is required on the basis of various factors such as, developed market for recycled fibres, post-consumer textile waste, the manufacturer of fabrics and various fashion brands. In the whole chain designing supply chain for textile industry in the closed system is the efficient way to make circular textile program sustainable. (The circular textile program, 2015)

- The circular textile program partners

In the circular textile project there are many partners which are contributing in the project according to their own area of expertise, to make this project more successful and to obtain the main objectives of the project. Partners of the project are listed below

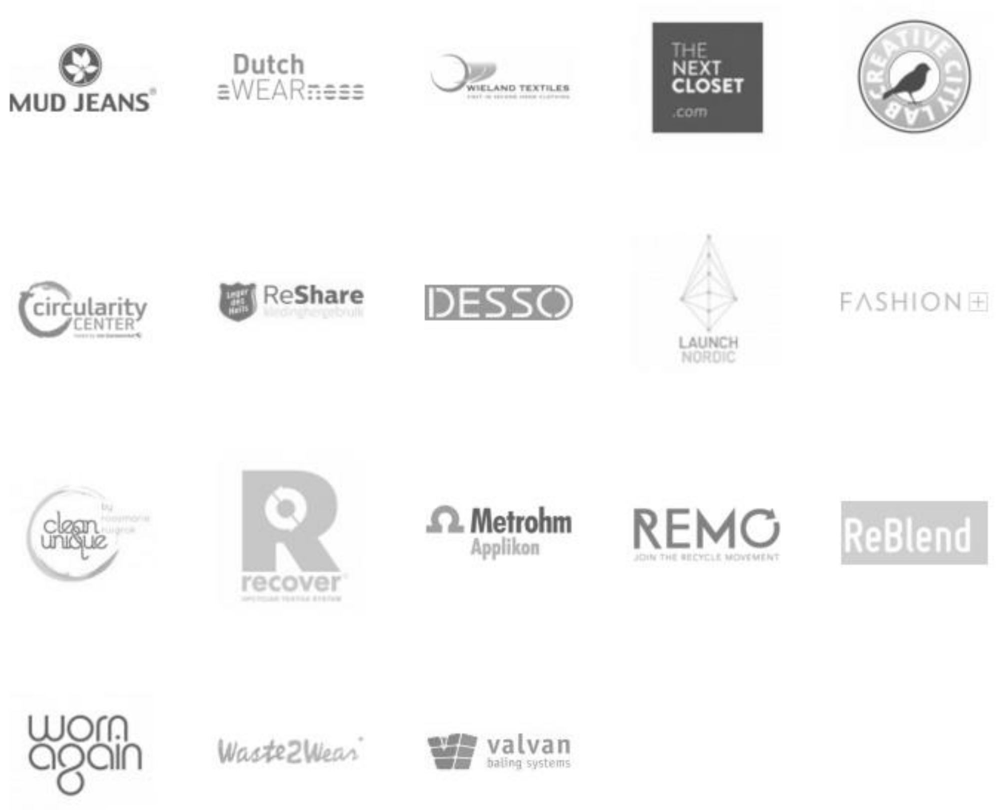

Figure 26: Textiles circular project partners (Circular Economy)

5.2.1 Circular Textile industry

Like other industries, current textile industry system is based on the linear economy system which means utilize available resources for new product and at the end of Product Life Cycle dispose of product to landfill or just to burn it. The linear based economy model based on the model is based on the expectation natural resources are easily available to utilized on the infinity level and at the end of old fashion clothing, they just can be thrown away. The fast fashion industry phenomena is one example to produce low cost clothes in high volumes which encourage fast disposability. (The circular textile program, 2015)

- Sympany Give well

In the textile circular program Sympany is the one of the main contributor in the textile recycling project. Sympany is a leading company in used clothe collecting in the Netherlands, Sympany is a new company with the merger of KICI and

Humana. Sympany is involved in gathering used clothes and textiles in all Dutch municipalities. (Sympany GEEF GOED Door 2015)

Sympany has different approaches to collect and recycle textiles and used clothes in cities and small places. Sympany has made textile collecting points where people can go and throw their unwanted clothes and other stuff. In addition to this, there is another approach to collect textiles which is in the retailer stores. People can drop their unwanted clothes and get some discounts on the shopping. When clothe bins are, transported through efficient transport system to recycling plant, where used clothes and other textiles are sorted out according to quality. Good quality clothes are separated and sent to developing countries where these can be reused, and low quality clothes are recycled and change into raw materials. Sympany is the contributor in the circular economy program, which means interesting to develop new systems from which environment and people can get benefits. (Sympany, GEEF GOED Door, 2015)

5.2.2 The Textile sorting project

This project is initiated to develop practical sorting expertise for commercial use. New developed techniques are used to identify the fibre composition of post-consumer recyclable materials and change post-consumer textiles into high quality of new fibres. The aim of automatic sorting of used textiles is to make the process of post-consumer textiles more sustainable and implement this sorting project on the large commercial scale for the sorting to use textile material with the FIBRESORT automated textile sorting machine. (The textiles sorting project, 2015)

5.2.3 Objective of the project and current situation

Optimization in sorting process machine sorting based on NIR technology to achieve accuracy for textile recycling for commercial use.

Improving the quality of valuable textiles which comes from post-consumers as well as creating new business opportunities for post-consumer textile and creating market demand.

Fibre composition of post-consumer textiles to access exact type of feedstock available for recycling. (The textiles sorting project, 2015)

5.2.4 Characterization of the project

The project of textile circular program was started by Wieland and circular economy, however, textiles circular project is under the process. Textiles sorting project is similar like earlier project was started textiles4textiles. In the FIBRESORT project the project partners are: Wieland Textiles, Valvan bailing systems Metrohm worn again Faritex and re-share (leger des heils) (The textiles sorting project, 2015)

- Appropriate feedstock for scalable chemical technologies

The mainstream of the textiles recycling technologies in efficient way is to make efficient and high class optimized technologies for sorting used textiles into high valuable fibres. In the high level recycling technologies with good and high quality of recycling systems and producing high level fibres out of textiles are required appropriate feedstock in the near future. On the other hand robust and scalable chemical recycling technologies are already in the advanced stage of development. To work in new technologies accurate and specific feedstock is required in the medium term (2-5) year. On the other end, mechanical technology based recycling options are already available in the market. (The textiles sorting project, 2015)

- Precision to Sort Post-Consumer Textiles

In the post-consumer textiles sorting, textiles are sorted accurately according to their fibre composition. At the moment manual textiles sorting is working accurately, which is based on the fibre composition. However, due to fast fashion industry and complex composition of textile materials, advanced technology is the requirement, to make sorting process quick on large volume. (The textiles sorting project, 2015)

5.2.5 Impact of Textile sorting project

In the planning phase of the project, there are two scenarios which are considered. In the first term two years are selected to see the outcome of the project. The expectations of this project are to contribute recycling industry over high recycled fibres for textiles-to-textiles in one year, the amount of total waste is about 2 million kg, and this has been estimated on the implementation of FIBRESORT machine in a new company for processing textiles into high quality. Processing total of 5 million kg of post-consumer renewable textiles every year, the total of 40% recycled fibre will change into high value clothing and fashion industry. It is estimated that new textile sort machine will also directly or indirectly will spark an increase of collection rates and further up-scaling of high value recycling. (Impact of Textile fibre sort project, 2015).

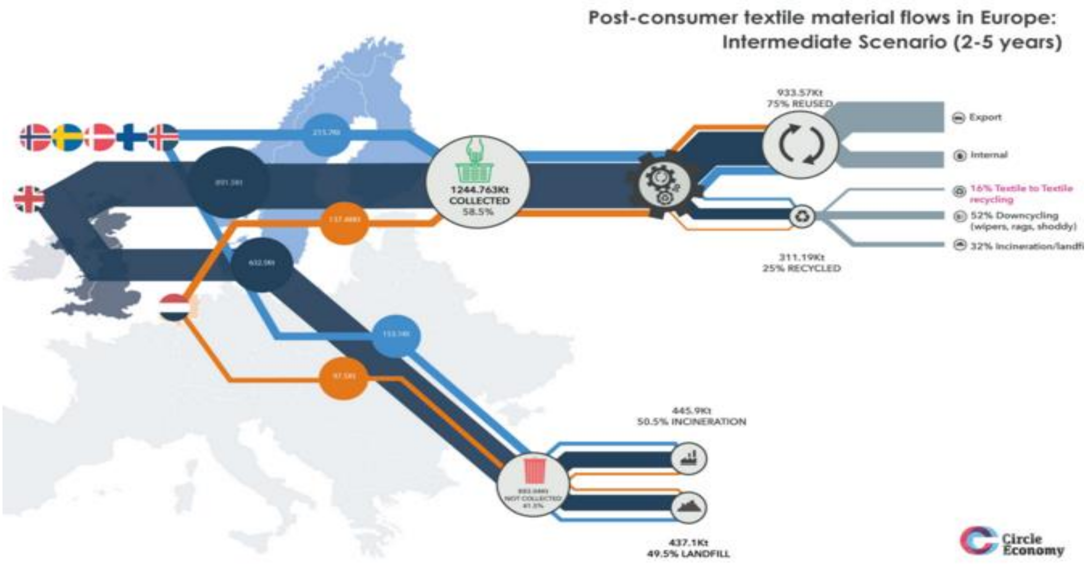

Figure 27: post-consumer textile flow in the Scandinavian countries and central Europe. (Textiles Circular program)

5.2.6 The Textiles sorting project partners

Important to achievement of this project is the association among different stakeholders in this value chain, which are based on their expertise. For example, management, technology companies, textile waste collectors, sorting companies and non-profit organizations. Post-consumer textiles is valuable resource rather than waste, working process and adapting new technologies and making new partnership is the essential success in the project. In the textiles sorting project, the value chain has been created with the participation of companies from various areas. (The textiles sorting project, 2015)

- WIELAND TEXTILES

WIELAND is a small company based in the Netherlands. The main area of the company is to sort second hand clothes. Annually sorted clothes are about 7 to 8 million Kg. Textiles4textiles was project in which WIDELAND participated, after the success of the project, company is now looking to use FIBRESORT machine in the near future. (The textiles sorting project, 2015)

- WORN AGAIN

Worn again is the company which is developing textiles to textiles chemical recycling technology. In the FIBRESORT machine project worn again is one of the main participant to develop technology and creating opportunities in the values chain. The main objective of the participation to understand potential in valuable feedstock for sustainable textiles sorting. (Abundance forever for everyone, 2015)

- Re-share

Re-share collects about 23 million Kg of used clothes annually. The main aim of the company is to develop more value and supply chain for textiles industry. After the revenue of the company spent its budget on the social programs like Salvation Army like other companies are participating in this kind of programs. (Re-share part of the Salvation Army, 2015)

- Valvan Baling Systems

In the FIBRESORT machine project Valvan baling systems is the designer and engineering system of the machine. The Company have expertise in the field of engineering to design hydraulic construction for baling presses and peripheral equipment. In addition, Valvan is also responsible for FIBRESORT machine marketing. (The textiles sorting project, 2015)

- Metrohm

Metrohm is the leader and modernizer of the new technology which is based on NIR spectroscopy scanning technology for automated textiles sorting FIBRESORT machine. NIR scanning technology is mainly based on the spectroscopic technique which means molecular absorption are measured in the near part of the spectrum. (The Textiles circular program, 2015)

5.3 Infrared spectroscopy applications in textile industry

5.3.1 Current technologies in textile sorting

The current method to sort textile is manual, however, there are technological options are also available for sorting textile and clothes with technology such as Radio Frequency identification, Fourier Transform infrared and Bar code tag.

- Manual Sorting

Manual technology is the binding technology. The textiles are sorted immediately by the operator who does the identification normally called manual sorting. In the manual sorting, there are many factors can be taken into account like, wide variety of colours, fibre, size. However, technology can make is more subjective textiles sorting based on quality, in contrary to this in the manual sorting there are limitations which means human can detect fibres and textiles only by touch and sight (Technologies for sorting end of life textiles, Humpston *et al*, 2014, 4-5).

- Bar codes

Bar code label are good to keep information about the textiles to make textile sorting process more efficient, for example black and white bar codes labels are read by scanner and decoded by computer. There is a need to do lot of work to identify the most appropriate data format for the bad code to verify the class of the textiles which is based on the materials. However, this process is so long and need to be well managed for accurate results. (Technologies for sorting end of life textiles, Humpston *et al*, 2014, 4-5)

- Fourier transform infra-red spectroscopy

FTIR is one of a family hyperspectral imaging techniques. FIIR has potential to detect fibre and cotton content of a textile. However, the technology is not developed at that point yet, but technological developments are underway on this stage. Recently it has been found that FTIR is the best alternate of manual sorting, and the FTIR based technology is already working (Technologies for sorting end of life textiles, Humpston *et al*, 2014, 4-5)

- RFID tags

RFID tags are used in the textile industry as Wireless USB memory stick which means RFID tags can carry data and it can be detect remotely from anywhere. These tags are made and designed for the manufacturer of the textiles which means tags are attached to the textile's products, and they travel with textiles throughout its life. In the tags the description of the textiles is sorted, on the arrival of the textiles in the store these tags are reprocessed and textiles are sorted according to their martial types. The very high value of stream can be processed specifically for sorting purpose. (Technologies for sorting end of life textiles, Humpston *et al*, 2014, 4-5)

5.3.2 Applications of FTIR in Textile industry

FTIR spectrometers are in the third generation, FTIR application has been widely used in structure elucidation that consist of either natural origin or synthesized chemically. The measurement technique is used in the FTIR spectroscopy to analyses electromagnetic radiation or other type of radiation. There are two main types of techniques which are based on spectra and coherence of a radiative source, while suing time domain or space domain. FTIR the applications are one of the best solution for analysing micro-samples through their speed and sensitivity, the FTIR unmatched as a problem-solving tool in organic analysis. The spectra library of FTIR microscopic tolerates few Nano gram of material to be gained rapidly, with little sample preparation and with lower cost. (Shaikh *et al, 2014*)

FTIR has two types of techniques to analyses organic and inorganic materials based on qualitative and quantitative analysis. Fourier Transform infrared detects chemical bonds in molecule by creating an infrared absorption spectrum. In the spectra library profile of sample is produced, in the spectra profile different components of sample are analysed. FTIR is a defective analytical instrument for detecting various type of materials and charactering covalent bonding information. (Intertek, Fourier Infrared Spectroscopy analysis, 2015)

6 NEAR-INFRARED SPECTROSCOPY TECHNOLOGY FOR TEXTILES 4 TEXTILES DEBUTS MACHINE AND FIBRESORT MACHINE

6.1 Background and general information

For consumers, sometimes it is difficult to decide which types of clothes are denoted and which to throw away. In the Netherlands, about 70 million kilos of waste is separately collected, whereas, 135 million of garments are going to waste. Two third of this perfectly fit for re-use or recycling, according to Dutch branch organizations for textiles collectors and recyclers.

- Background of Textiles4Textiles project

High standards of fashions and increasing demand of textiles has put lot of pressure on the textile's industry. On the global scale textiles industry is understood one of the polluting industry. The production process use up natural resources and create high impact on the environment during production process with the enormous consumption of water and pesticides. Technological advancements in the recycling of post-consumers garments and textiles is a way to lower the negative impacts. Since the cost of material is very low and sorting different fibres have high prices and complexity in fibres sorting. To make textiles sorting process more efficient and automated, textles4textiles project was initiated and it has been completed to enable a higher values of second hand garments and textiles. Textiles automatic Debuts sorting machine sort both types of fibre which are based on their composition and colour. (Eco-innovation, Textiles4Textiles, 2015, 1)

Fashion2 project was started in summer 2012, the purpose of the project was to motivated and give awareness to Dutch citizens to bring their used clothes to the shops and collection centres to avoid landfill. Also the design closed loop system for textiles recycling. In the closed system used clothes are sorted out and recycled and from recycled material new fibers and clothes are made. The main challenge was to find out the best solutions for sorting textiles, which make more efficient sorting process and cheap as well. 50% of the used clothes are good enough in quality that they can be sold out and other 50% are used for low quality of textiles, such as insulation materials and wiping clothes. Manually sorting clothes are not profitable since cost of sorting is higher than sales price of the used clothes. That’s why advancement in technology was required in the textile sector to sort out clothes automatically. (Textiles4Textiles automatic sorting machine for recycling and used apparels, 2015)

6.1.1 Automated textiles sorting machine requirement for better performance

Textiles waste is a valuable material which can be utilized for various purpose to safe natural resources. Furthermore, the value of textiles fibers is even more efficient when fibres are recycled and sorted according to their colours and composition of fibres. Mostly, post-consumer non-warebale textiles have frequently difference in their fibres materials. Furthermore, the sorting process and manually sorting in the EU and USA are more expensive than the original value of the post-consumer textiles. There are possibilities to outsource textiles sorting services logistics and transportation cost implies too much. To make more efficient and environmental friendly technologies are required to make this process more efficient. Hence, automated textiles sorting machine is already in the market. (Textiles4Textiles, 2012, 6)

6.2 Textiles4Textiles automatic textiles sorting machine

The main purpose of the Textiles 4 Textiles project was to introduce automatic machine for textiles sorting by consortium of SMEs under the project Textiles4Textiles. The SMEs were involved in this project were from chain of second-hand textiles collection sorting, manufacturing and recycling. Main partners of the project were KICI and Wieland which are biggest used clothes collection and sorting in the Netherlands. The objective of the project was achieved and Debut automated textiles sorting machine has made new development in the area of textile recycling. Debut automatic textiles sorting machine has made possible to sort out low quality of textiles into high value recycle materials, which means. The efficient way of sorting textile by automatic sorting machine with 100% cotton, this technology has made potential to production of jeans. The raw material for making jeans is collected from recycled fibres from post-consumer fibre cloth waste. (Textiles4Textiles automatic sorting machine for recycling and used apparels, 2015)

Figure 27: Textiles4Textile automatic textiles sorting Machine. (Snapshot is taken from YouTube video which is made for Textiles4Textiles automatic textiles sorting machine, 2015)

6.2.1 Textiles sorting Debut machine working principles

Automated textiles sorting machine has been invented under the project Textiles4Textiles which was completed in 2013 using NIR techniques for sorting textiles by the composition of fibres and colour. In the Debut machine NIR spectroscopy infrared lights are used which detect the fibre and sort it out accordingly. In the sorting process analytical applications are used with NIR spectrometer. NIR spectrum detect the complete measurement of the moving object in the processing time. Photons, sensors and vibrational techniques are used to identify and sort out fibres- The same technology has been used in the Debut automated textiles sorting machines. The main technologies which are used in the Textiles4Textiles project are based on NIR technologies.

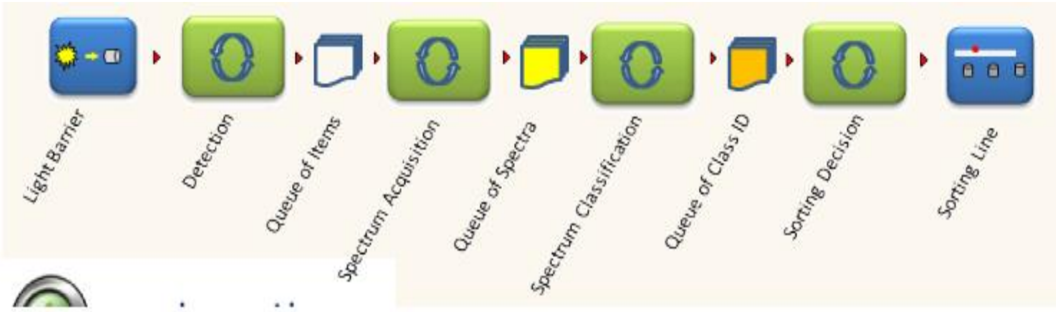

Figure 28: Textiles sorting based on their material and colours. (Textiles4Textiles, 2012)

The above figure shows the working principles of the Debut Textiles4Textiles machine. At the beginning level clothes are placed on the conveyer belt and light barrier is there to start to process textile. Passing through light barrier the next step is detections where textiles is detected and identified its fibre and colour type. In this step there is another technology, which is used to identify the textiles in optical detection technology in FIBRESORT. In the next process textiles are placed in the queue to make spectrum acquisition while the next step is to wait for further processing where library of spectra is used to find out the fibre and colour type from its spectral library database. Spectrum classification is the next step where classification of fibre and its colour are made, data which is obtained from the spectra library. After the processing is made, the next stage is queue of the class ID, which is obtained from spectra library to give specific ID to the colours and fibres types. In the final process, decision is made from which class fibre belongs to. However, in the sorting machine instructions are given according ´to automatic and manual instructions which are given by the users. (Textiles4Textiles, Anukein, 2012, 5)

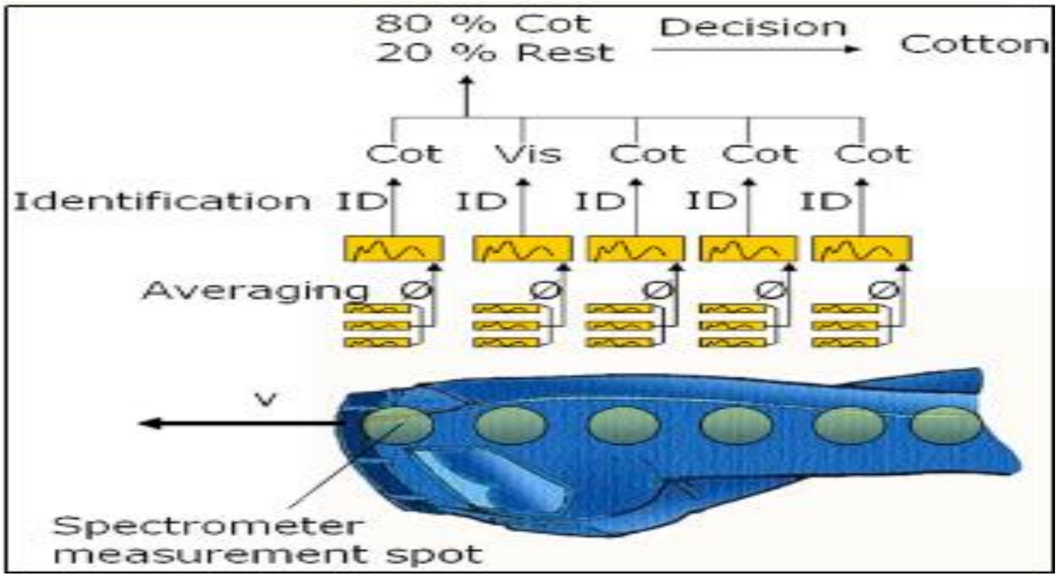

Figure 29: Machine working principles for detection textiles is shown using Near-infrared identification technology and optical detection technology. (Textiles4Textiles, 2012, 5)

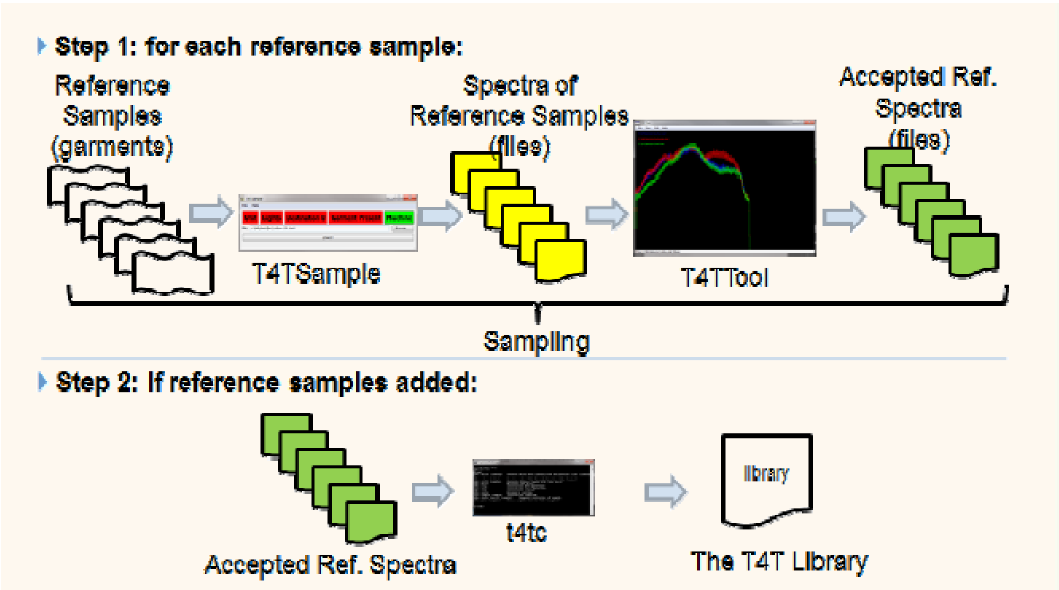

Figure 30: steps for sorting textiles based on colours and fibres are shown in the above give figure. (Eco-innovation lab, 2012. 13)

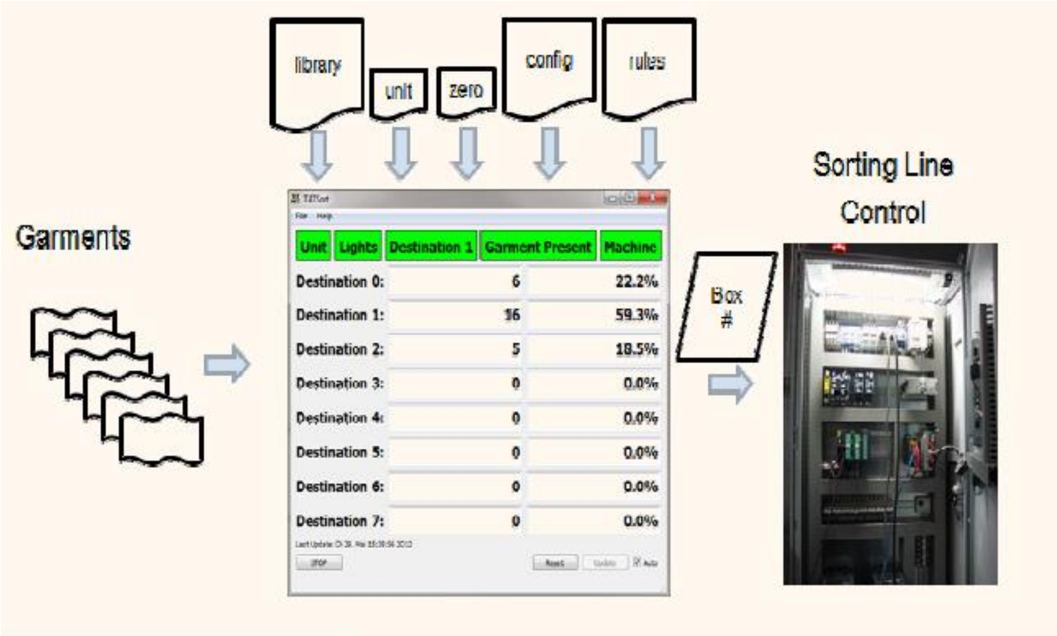

Figure 31: figure show the process of sorting and working principles of Debut machine. (Eco-innovation, 2012. 16)

Further detail is given for the processing of Debut machine and sorting clothes based on fibres and colours.

IDENTIFIED SPECTRA IN ACCEPTED SPECTRA

Samples	Total	Unknown (%)	Belt (%)	Cotton (%)	Acrylics (%)	Wool (%)	Poly-ester (%)	Cotton / Acrylics (%)	Acrylics / Wool (%)
Belt	86	41	59						
Cotton	1027	2		**94**		3		1	
Acrylics	695	3			**94**	1		1	3
Wool	899	4		2		**90**			3
Polyester	452	9					**90**		
Cotton/ Acrylics	401	6		5		5		**82**	1
Acrylics/ Wool	487	1			3	19		7	**70**

Figure 32: In figure is shown the identified spectra in accepted spectra. (Eco-innovation, 2012)

In this project NIR is a main identification technology, NIR-spectrum is different for each kind of material to identify materials specifications. To analyse the materials and sort them out in their own material types, library of spectra is created for each types of materials and its standardizations for sorting process. NIR for identification purposes, to analyse different kind of material NIR spectrum is used. In this machine, library of spectra database has been created to identify fibres and sort them according to their fibres and colours type (Luiken, Textiles4Textiles, 2012, 12)

6.2.2 Specification of Debut automatic cloth sorting machine

The technology is based on the spectrometer and sensors which detect the fibre and sort out, the major specification and working principles are given here.

Measurement rate more than 20 spectra per second.

The spectral range of VIS is from 300-700nm (nanometres)

In the near-infrared spectrum the range of detection of material is from 1300-1700nm.

Optical Resolution in the near-infrared is about 15nanometers

In the visible light of the VIS (Visible spectrum) is about 7nm.

Measurement rate is from distance probe head- sample 40-80cm (centimetre) (Testiles4Textiles, Eco-innovation, 2015).

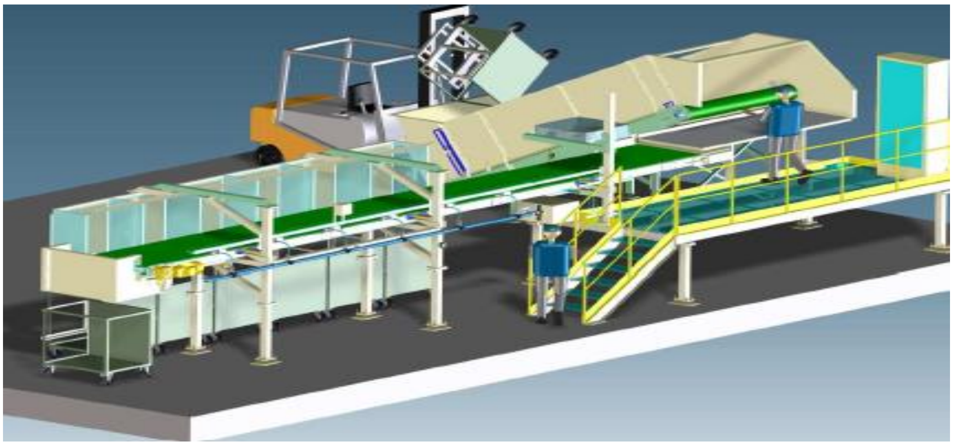

Figure 33: Debut automatic cloth sorting machine is shown. (Textiles4Textiles, Eco-innovation, 2015)

- Optical detection system for Debut machine.

In the Debut textiles4texitels machine optical fibre detection system is used, which detect textiles according to their materials and colours.

- Spectra Library of IR
- NIR spectrum
- Sensors
- Spectrometer

These are the main techniques both analytical and technological are used in Debut machine. Spectral library of IR is specially created for Debut machine. On the other hand of this Near-infrared spectrum is used from spectroscopy aspect as well as from laser detection and identifications are used. Spectrometers and sensors are combined in the identification process which obtained data from spectra library of IR.

6.2.3 Manufacturing cost of Textiles4Textiles

The manufacturing cost of the machine is not so much if it is created with collaboration of partners already working in the same project. In the table is shown the cost of Textiles4Textiles automated sorting machine.

Table 5: In the table is shown the total cost and fixed cost of the textiles4textiles automated sorting machine. (Eco-innovation, 2015)

Investment (Machine) approx.	€	431.000
Fixed Costs per year		
Depreciation (10 years)	€	43.100
Interest 50%	€	12.930
Maintenance	€	12.930
Annual updates library	€	3.500
Annual costs space (€50,- m2)	€	35.000
Total fixed costs per year	**€**	**107.460**

Textiles4Textiles machine replaced manpower in the sorting industry. Before there were many people use dot work in the warehouse to sort clothes, now only 1-3 people can work in the cloth sorting. Table is given below to show the difference in manual sorting and automated sorting clothes.

Table 6: indicate total annual cost of man power in textiles sorting. (Textiles4Textiles, 2012)

Manpower		
Operators per shift		1,5
Operator costs per year	€	25.000
Total costs per shift per year	**€**	**37.500**

Annual cost of Textiles4Textiles shows that minimal cost of textiles sorting need to be little extra per kg, which is minimum 0.02-0.04 Kg to compensate for the extra cost of sorting.

Table 7: Table shows the annual cost of Textiles4Textiles automated textiles sorting machine. (Textiles4Textiles, 2012)

Sorting capacity/year											
		Energy		**Manpower**		**Fixed costs**		**Total costs**		**Cost per kg**
shifts	KG	euro/year						(Euro/yr)		(€/kg)
1	4.147.200	€	20.736	€	37.500	€	107.460	€	165.696	0,040
2	8.294.400	€	41.472	€	75.000	€	107.460	€	223.932	0,027
3	12.441.600	€	62.208	€	112.500	€	107.460	€	282.168	0,023

6.2.4 Cost of Textiles4Textiles and Return over Investment

The study shows the price of textiles sorted materials have commercial values between 0.30-0.50 per kilo with 100% materials and other mixed fibres/textiles.

It is investigated, the total amount of machine return over investment is about 2.1 years. If the machine is used in two shifts, the total cost of return over investment will decrease within 2 years and total time payback for machine can be sharply decreased. However, this is possible for other companies to rent out the machine and use it for their purposes. It is commercially used for third party.

Table 8: Return over investment table is shown for Textiles4Textiles textiles sorting machine. (Textiles4Textiles, 2012)

# shifts	kg sorted per yr	Investment (euro)	extra yield per kg (euro)	Extra yield per year (euro)	R O I (years)
1	4.147.200	431.000	0,050	207.552	2,076588
2	8.294.400	431.000	0,063	522.564	0,8247794
3	12.441.600	431.000	0,067	837.576	0,5145802

- Partners for Textiles4Textiles project

Wieland, Wieland is responsible for sorting process and Textiles4Textiles Debut machine is installed in the Wieland used clothes recycling and collection at Wieland in Netherlands.

- KICI is the biggest company in collecting used clothes across the country, in the Textiles4Textiles automated sorting machine KICI is one of the main contributor.
-
- To develop hardware for Debut NIR technology based technology for clothe sorting MUT AG is responsible for developing hardware for NIR technology.
- Frankenhuis has specialization in the area of handling second hand textiles and recycling textiles into fibres.

- Groenendijk Bedriifskleding has expertise to collect labour apparels and these collected work wear in which post-consumer recycled fibres are used.
- Work on Progress is the company has developed product development of Debut machine.
- Wieland Textiles is textiles sorting company, currently Debut textiles sorting machine is working in the Wieland premises in the Netherlands.
- Enviu is the company which is responsible for the promotion of the machine.

In the finding it has been shown in the textile industry innovation has been made with the help of companies from various fields in other words it called value chain. There are still further developments are required for this project.

6.2.5 Financial support

To keep this innovative project by the constrain SMEs, project was funded by the European Union from eco-innovation program. The purpose of eco-innovation program was to give clear view and to see the potential in the EU. Also to develop and sustain more environmental friendly textiles and other areas of the industries. Hence, under the eco-innovation program textiles4textiles project was initiated to bring new ideas, and certain new possibilities for textile industry. Also creating jobs in the textile sorting while at the same time make sorting process more efficient with the help of NIR and other technologies in the textiles recycling industries. In addition, finding more efficient way to reduce negative impacts of production of new fibers for textile industry.

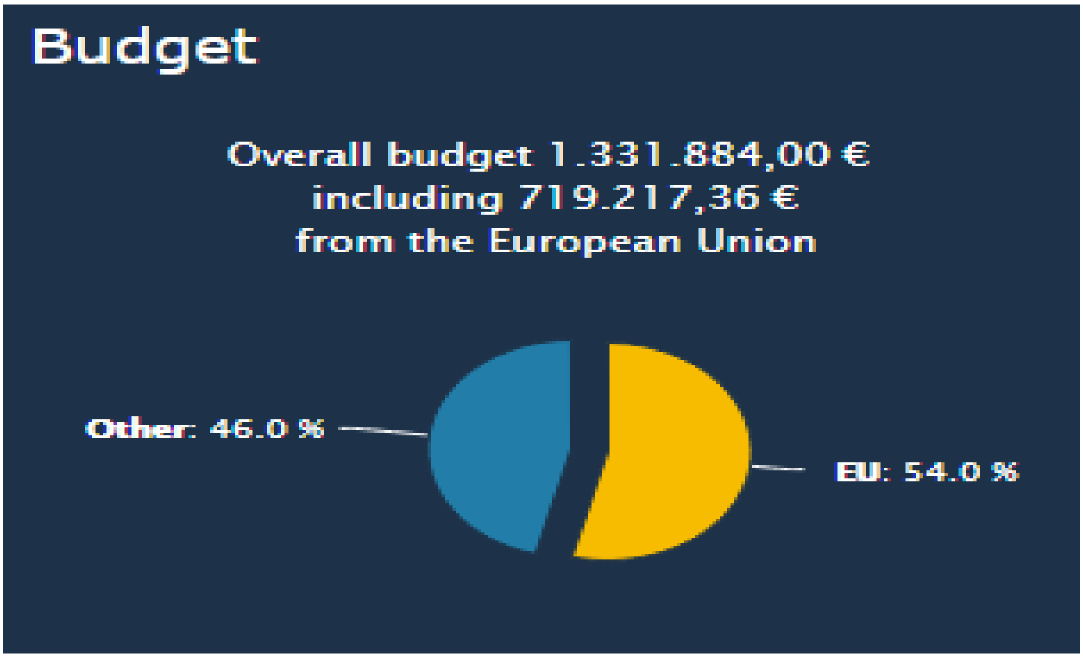

Figure 34: Figure shows the total budget and contribution to project for textiles4textile. (Eco-innovation, 2012)

6.3 Results

With the Textiles4 textiles project there is positive change on environment, creating new jobs as well as economic growth sounds good. According to UK based research company Ipsos Mori, recycling is a success story with rapid change in the part of the country. In qualitative research the people of England were asked whether their used clothes go recycling or just simply landfilling. Similarly in the Netherlands there was another survey to conduct the research based on textiles recycling to see the results from modern technology based applications in textile recycling industry.

- NIR spectrum detect the complete measurement of the moving object in the processing time. Photons, sensors and vibrational techniques are used to identify and sort out fibres.
- To the sorting machine instructions are given according ´to automatic and manual instructions which are given by the users.
- The Debut machine has positive impact on the environment through automated textiles sorting process based on composition of fibres and

materials like wool cotton and polyester are not required to re-dying at the time of making new textiles from recycled materials.

- Re-dying textiles is one of the most expensive and unfriendly to environment, with the Debut textile sorting based on fibers and colour save cost as well as environmental impacts.

- Creation of new business opportunities in the textiles value chain for textiles recycling and fashion brands.

- Debut creates new business opportunities to make new textiles from post-consumer textiles waste. (Textiles4Textiles, 2012)

6.3.1 Environmental impact.

Through fibre detection based on colours and material composition of fibre are sorted in the Debut machine. However, there are environmental impacts of Debut machine in the sorting clothes, environmental impacts are given in the categories and classification of fibres.

- Class A

In the first category the environmental impact of recycling cotton, nylon, polyester organic hemp and organic flax are included. These fibres have huge negative impact on the environment at the time of production while using Debut textiles sorting machine is the solution to safe natural resources which can be used later on other purpose than virgin fibre production.

- Class B

In this category there are another kinds of fibres like Tencel, organic cotton in conservation cotton which are complex in composition. These have negative impacts on the environment.

- Class C

Conventional hemp Ramee pla conventional flax (linen) are sorted by Debut machine and the production of these fibres reduce burden on the natural resources.

- Class D

Virgin polyester poly-acrylic and Lenzing modal quality is improved and reduced the amount of water and fertilizers for production process.

- Class E

Conventional cotton, virgin nylon Bamboo-viscose, wool and generic viscose have negative impacts on the natural resources. However, Textiles4 Textiles Debut machine has made possible at least to safe certain amount of negative environmental impacts.

- Unclassified

In the Debut machine spectra library for identification of fibres database is made, still there are fibres Silk, organic wool, cashmore, acetate, leather and elastane which are not identified in the spectra. However, these fibres are classified still in the mixed waste from where materials for rags and carpets are made. (Textiles4Textiles, Luiken. 7, 2012)

6.4 FIBRESORT Automated textiles sorting machine

There are two main companies involved in innovating FIBRESORT automated textiles sorting machine under the textiles automated sorting project. Metrohm is developing NIR technology in their research and innovation centres to complete successfully FIBRESORT project. With advanced engineering techniques VALVAN Baling systems has designed and make FIBRESORT for commercial use. In this chapter FIBRESORT machine’s technical and working principles are conferred in detail, On the other hand both companies’ scientific and engineering techniques are discussed shortly.

6.4.1 Metrohm

Metrohm is one of the leading manufacturer in the field of high-precision instruments for chemical analysis as well as analytical instruments for titration. Dutch Metrohm branch is more focusing on the recent technologies in the field of automobile manufacturer instruments for electrochemical research. In this thesis the main applications for textiles sorting and fibre analysing are discussed due to limitations of the thesis (Ons bedrijf, company information, 2015)

6.4.2 Metrohm Spectroscopies

Near-infrared spectroscopy application is the recent innovation used for textiles automated sorting purposes. Raman and NIR are the main area of expertise of Metrohm. NIR analyser are ideal for normal analysis of chemicals as well as physical properties of samples in the laboratory. (NIR Systems spectroscopy solutions, 2015)

There are two main categories of spectroscopy and various other applications are used in these methods.

- NIR System laboratory analyser

NIR technology is protected by near-infrared scanning technology which provides accuracy during entire analysis process, NIR analyser provide hot swappable measurement tools easy to use and flexibility in sampling. (NIRS lab analyser, 2015)

Figure 35: NIR system analyser for analysing chemical samples in the laboratory. (Metrohm, analyser, 2014)

Main features of the NIR system analyser

- Different measurement techniques are possible with NIR
- Laboratory instruments are also used for the monitoring of reactions.
- Extensive automation for trays of tables and vials.
- Patented modular monochromatic and accessories for sampling like cuvettes and probes can cope all kind of ogres. (NIRS lab analyser, 2015)

- Instant Raman analyser Mira

Instant Raman analyser is fully equipped with dual core mobile spectrometers with orbital Grid scan technology. Raman analyser spectrometers are fully equipped with validated spectrum libraries for maximum usability and feasibility. Mira analyser system is specially designed for complex samples to analyse. However, Mira Raman analyser are also used of liquids and gases samples. (Metrohm instant Raman analyser: Mira, 2015)

Main features of Instant Raman analyser

- Direct and intuitive fast in decision making even in complex samples.
- Versatile in use anywhere and everywhere its applications are ready to sue
- Powerful the stand by time is 11 hours with A4 batteries.
- There are with the range of 785nm for non-fluorescent and 1064 nm laser fluorescent samples.
- Maximum security for using integrated vial holder, point and shoot option for translucent container.

Metrohm has developed 50 more applications for textiles industry based on near-infrared spectroscopy spectra. Through new applications, blend analysis of polymers and fibre can be analysed. These analytical techniques can be used online also with the help of software. (NIR collected applications for textiles industry, 2015)

6.4.3 Analysis of textiles using Near-infrared spectroscopy

NIR technology has been used in the textiles widely to analysis textiles and structure of fibres in various phases of textiles manufacturing process. In this section analysis of textiles is investigated while using NIR.

- Monitoring percent on finish polyester

The outcome of the used analysis on polyester through NIR which shows the percentage of fluorocarbon on polyester, the total range of sample concertation is about 0.08%-0.367% fluorine.

- Sampling

Sample is analysed in the reflectance mode from 1100-2500 nm spectral range, there are many other techniques are used in this process to analyses sample using NIR spectra.

- Results

Results shows that NIR spectroscopy can be used to analyse fluorocarbon based finish in polyesters. The main issue in this process is to analyse samples, therefore there should be no errors in the sampling Preparation. (Analysis of textiles using near-infrared spectroscopy, 2015, 6)

- Finish oil on fibres

NIRS applications shows the total amount of oil on finish fibres. In this process sixteen samples are analysed with finish content ranging from 0.136-0.825%. The information also provides the structure of the fibre, raw material and oil based emulsion.

- Sampling preparation

In the sampling analysing process 1100-2500nm intractance reflectance probe is used, each sample was analysed six times to find accurate results while reposition the scanned samples. To find oil different quantity in the fibres 1350-2380 nm reflectance method is used, in the finish oil on fibre showed the five factors on chemical system.

- Results

The sampling results shows that NIR can be sued to find finish oil on fibres. (Analysis of textiles using near-infrared spectroscopy, 2015, 6)

- Polyester in cotton blend

To analyse polyesters in the cotton blend, quantitative approach is used to analysis the quantity of polyesters in cotton blend. There are 35 samples which was analysed and the quantity of polyesters in cotton blend was about 44-57%.

- Sampling

NIR spectra is used in reflectance mood, using spinning cup modular. Samples are scanned in the range of 1100-2500nm wavelength region. Three samples are used in this method to find accurate results while other reflectance method was used in the 1660nm wavelength.

- Results

Results shows that NIR spectroscopy can be used to analyse the percent of polyesters in the blend cotton, which means NIR spectroscopy is a successful innovation to sort out fibres and clothes based on their materials. (Analysis of textiles using near-infrared spectroscopy, 2015, 7)

- Moisture and oil content in wool fibre

NIRS can be used to analyse the oil and moisture content in the wool fibres. The moisture charge in the wool fibre is about 16-17%, so this application is useful for analysis of wool fibres.

- Sample

Sample are analysed in the reflectance mood in the wavelength region from 1100-2500nm, while coarse cells are utilized in the sampling process. On the other hand to find out the moisture in the wool content two spectral region is used. The spectral region of spectra is 1440-1920nm, to find other sample the spectra is 1436-2266nm.

- Results

The results indicate that NIRS can be used to monitor the moisture and oil content in the wool fibre. (Analysis of textiles using near-infrared spectroscopy, 2015, 8)

- Distinguishing nylon, polyester and polypropylene threads

NIRS applications are used to analyse different types of fibres and distinguishing between fibres. To achieve the required target, some analyser are used to identify the problem and separation and quantity of fibres in the mixed textiles. The analyser for fibres and other textiles are made by Metrohm, applications of NIR and NIRS are investigated for various purpose. (Analysis of textiles using near-infrared spectroscopy, 2015, 3)

- Sample

In this process spinning sample methods are sued in the region 1100-2500nm wavelength. In the process spectral differences are viewed very easily throughout the NIR spectral. Moreover, IQ2 is used for identification purposes with the region 1150-2450nm, also all the samples are analysed to determine their identity.

- Results

It is found that NIR can be used to identify various types of blended and non-blended fibres. The better method to identify fibres is to use different ratio in different fibres. (Analysis of textiles using near-infrared spectroscopy, 2015, 3)

6.4.4 Future Near-infrared spectroscopy technology for textiles

Metrohm is the leader and innovator of the new technology which is based on NIR spectroscopy scanning technology for automated textiles sorting

FIBRESORT machine. NIR scanning technology is mainly based on the spectroscopic technique, spectroscopic techniques are based on the absorption of molecular which is measured near part of the spectrum. The analytical technique is sensitive to organic constituent, since all textiles are composed of cotton, there is no obstacle and limits to sort fibre based on their composition (Circular textile program, FIBRESORT, 2015)

6.5 Valvan Baling System FIBRESORT machine maker

In the textiles circular program Valvan is the manufacturer of FIBRESORT machine for automated clothes sorting, according to their fibres. Valvan has worked on engineering design and marking of FIBRESORT machine.

6.5.1 Current used clothing handling systems at Valvan

Valvan has good system to handle used clothing in the shape of bails. However, this process is done after used clothe are sorted. In the first phase used clothes are sorted out. When sorting is completed these clothes are pressed and bails are made, which is easy to transport and for recycling purposes. Thus, Valvan has solution to handle used clothes with the help of its technological advancement.

- Feeding Systems

In the feeding system five techniques are used to handle bails at the recycling plant which are mentioned here.

- Bale opening system

This process can be done with bale destrapping belt, where straps are cut into small’s pieces and material start to move itself, tilting technique is useful to handle this kind of systems as well. (Bale opening Systems. Valvan, 2015)

- Automatic uploading trailers

Materials are stored in the containers, efficient way to uploading container is automatic uploading systems. Valvan is using same kind of techniques to upload container by conveyers, automatic uploading process is similar like automatic sorting techniques for used clothes. (Automated uploading system for baling, Valvan, 2015)

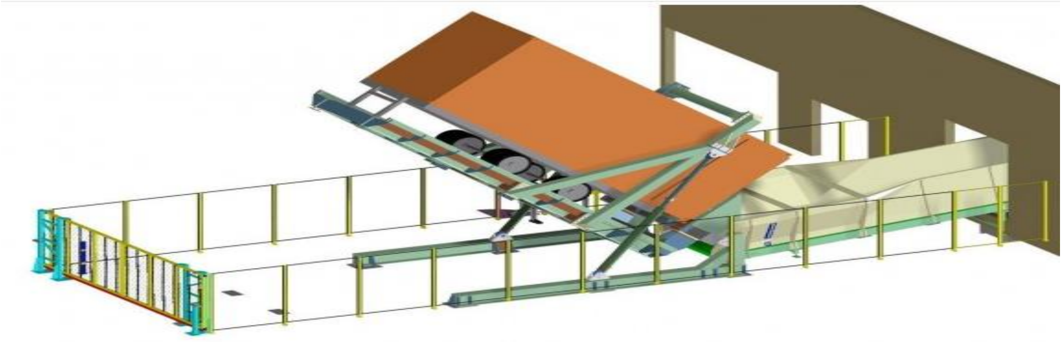

Figure 36: In the image container on automatic uploading system is shown, where whole container is placed on the heavy conveyer. The figure is taken from Valvan Automatic uploading category page.

- Robot Feeding system

Robot feeding system is used to provide feedstuff to serval sorters from the same source, the device consist of a conveyer belt which moves on the rail in more than one direction. Integrated Weighing systems are used to keep track the production of each sorter that receive material. (Robot Feeding System, 2015)

Figure 37: The robot feeding systems for used clothe sorting. (Valvan Baling system, 2015)

6.5.2 Sorting Equipments

- Manual sorting

Manual sorting is a slow process, and it is used for slow production, sorting is done manually and sorted clothes are placed in the carts or on the table. The manual sorting process is not efficient, to make more efficient we are required to have automated and technological used clothes sorting method.

- Belt sorting systems

With the advancement of technology in sorting clothes belt sorting system for clothes is better compare to manually. It is estimated that 20 tonnes of clothes can be sorted in one shift. However, belt soring method for sorting clothes is ideal mainly for production purposes which means right after sorting clothes are going in the right categories for recycling. There are categories as well to sort clothes. (Belt sorting System, Valvan, 2015)

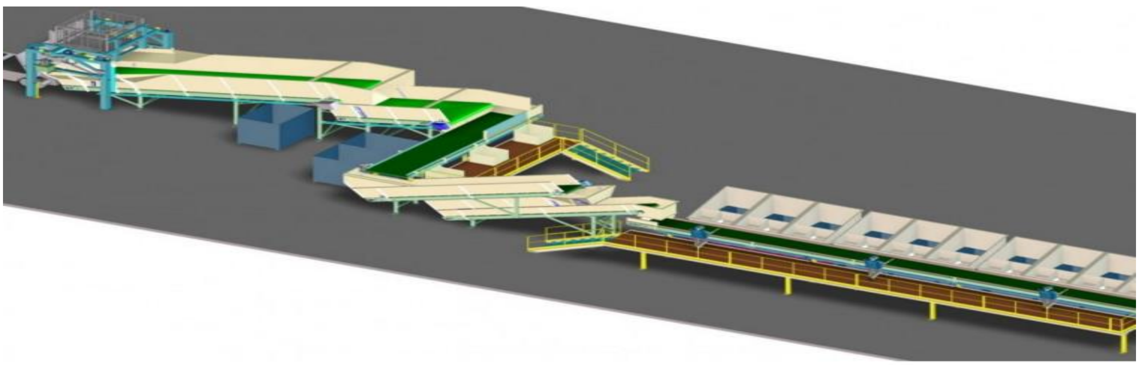

Figure 38: The belt sorting system for further processing of clothes. (Valvan baling system, Belt sorting system, 2015)

- From Sorting to Baling

From sorting to baling is one of the crucial process, normally clothes are sorted out at one plant. Used clothes are required to send to another location for further processing. For this purpose baling is the efficient way for recycling used clothes.

Valvan has efficient automated baling technology for sorted clothes. This is one of the best solution for efficient way of recycling textiles according to their structure of fibres. (From sorting to baling, Valvan, 2015).

- Speech sorting systems

Speech recognition technology for sorting textiles is one of the efficient and best technology available at the moment.

In the speech recognition technology microphones are used by the users while using voice recognition system to identified the clothes category. The item is dropped next to the sorter on the belt where it's further recognition is required by the recognition control system.

The biggest advantage of this system is that sorting capacity is unlimited, but it's depend on the sorter which means the accuracy and speed can be down as well. The software for speech recognition is available almost in most of the world language which means language is not the issue in this process. (Speech Sorting systems, Valvan, 2015)

Figure 39: Used clothes are sorted with speech sorting system.

6.6 FIBRESORT Machine New innovation

Before, FIBRESORT innovation valuable and pure fibres were going to down cycling for recycling, the time has changed with technological advancements in the textile's industry. Valvan Baling system introduce new technology FIBRESORT which enables the recycling industry to identify and spate textiles based on their fibres. (FIBRESORT Valvan, 2015)

6.6.1 New NIR technology for FIBRESORT

In FIBRESORT automated textiles sorting machine is based on scanning technology in which NIR spectroscopy technology is used. Moreover, spectroscopic techniques are based on molecular absorption which are measured in the Near-infrared part of spectrum. (FIBRESORT Valvan, 2015)

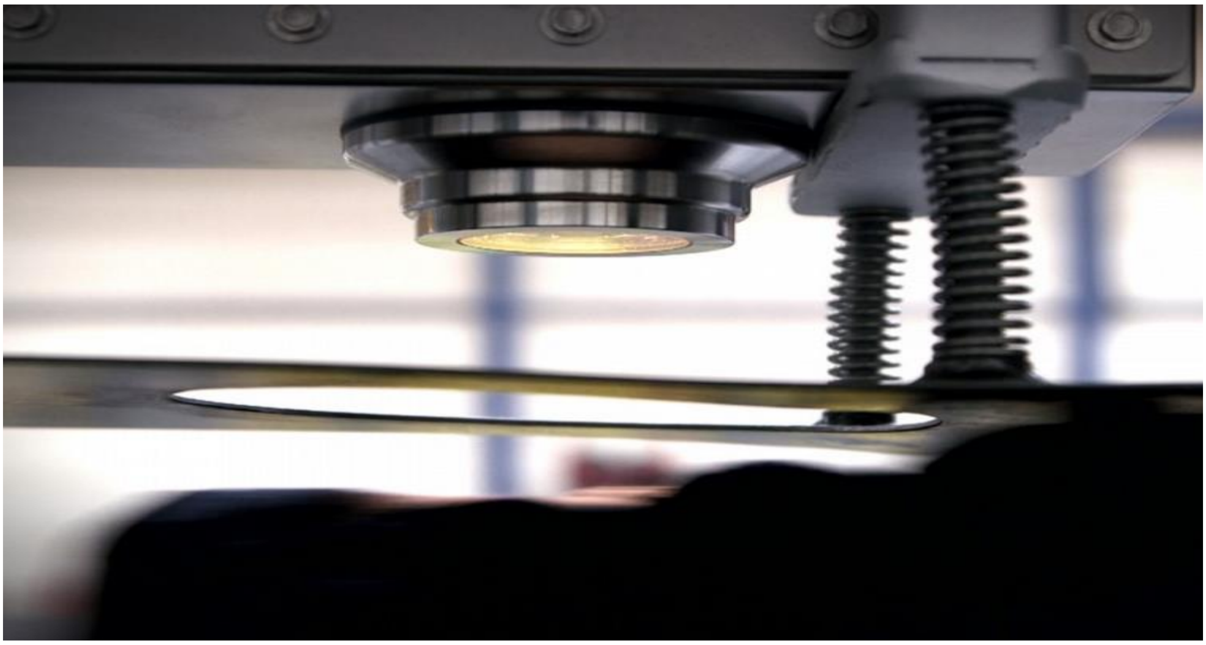

Figure 40: The NIR spectrum in which molecular absorption is measured. When fibre cross under the spectrum, spectroscopic technique immediately identify the materials of fibres. (Valvan, FIBRESORT, 2015)

6.6.2 NIR Spectrum techniques without limits

New technology which is based on NIR spectrum is sensitive to organic constituents, on the other hand all textiles are organic, and there is no limit to the fibres that can be recognized.

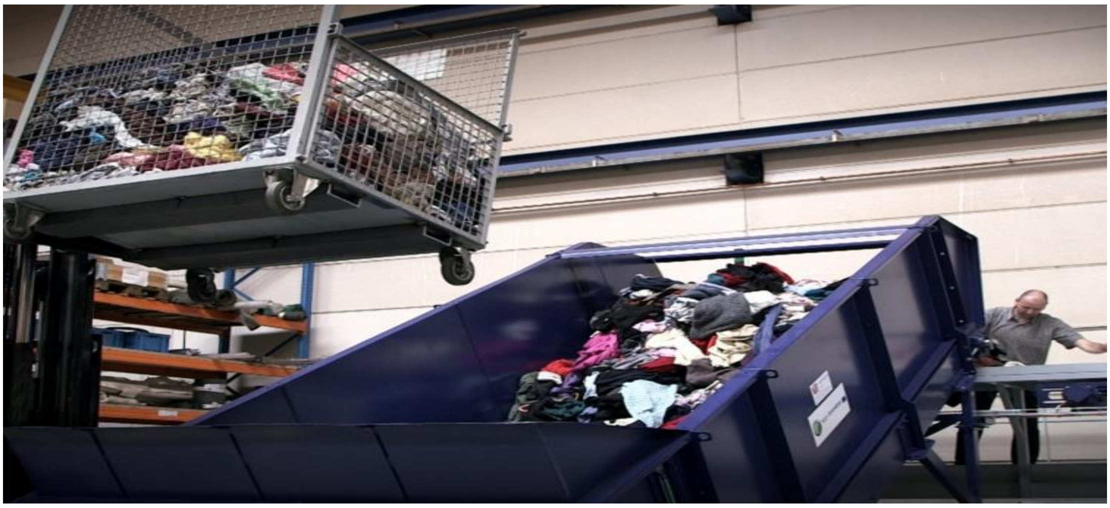

Figure 41: The sorting process for unlimited textiles which are organic fibres, there is no obstacles and limitations to sort textiles under NIR spectrum. (FIBRESORT, 2015)

6.6.3 Supply of textiles for FIBRESORT

In the process one piece of textiles is required at time to process, the supply of textiles to the system must be one by one pieces. This process can be done manually be an operator which take the items for stack and put them piece by piece on the conveyor. (FIBRESORT, 2015).

Figure 42: The sorting process of textiles is automated, scanning must be done piece by piece on the conveyor. (FIBRESORT, 2015)

The supply of the textiles on the conveyor must be manually done to scan textiles.

Figure 43: Above figure shows that after manually textiles is reached to the system, system scan the fibre and identify the fibre and its structure.

6.6.4 Sustainability in textiles recycling through FIBRESORT

Through FIBRESORT sustainability is driven in the textile industry. In the sorting process when fibres type is determined, next phase is textiles are sorted automatically by pressurized air into corresponding category, the number of category is unlimited. (Sustainable textile recycling, FIBRESORT, 2015. 2)

Figure 44: In the above figure is shown that after detecting fibre type with pressurized air textiles are sorted according to their material and category, place them in the different bins. (FIBRESORT, 2015)

6.6.5 Current capacity of FIBRESORT and future development

At the moment FIBRESORT capacity is piece by piece per second with further research and development, Valvan is expecting to increase the operational capacity in the near future. After the development innovation of the FIBRESORT, Valvan has made extensive textiles databases and library to determine fibres, cotton, wool, polyester, and acrylic and even blend fibres. (Sustainable textile recycling, FIBRESORT, 2015. 2)

6.6.6 Further development in FIBRESORT

Valvan has already taken steps in enormous areas of technology for another kind organic fibres further testing with textiles of the required fibres, the experiment are already being done at Valvan premises. Textiles automated sorting through FIBRESORT is an anticipated. (Sustainable in Textiles recycling, FIBRESORT, 2015. 2)

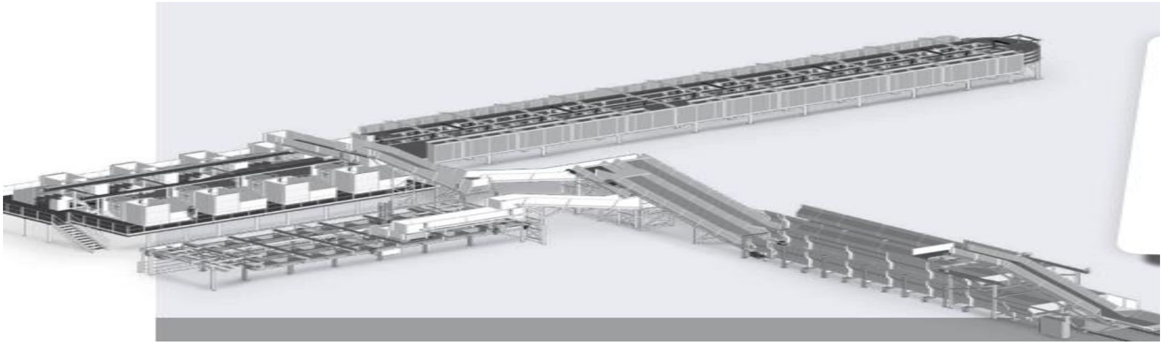

Figure 45: Future FIBRESORT machine is shown in the figure. (Valvan, FIBRESORT, 2015)

Valvan is already working on FIBRESORT biggest project to increase capacity and large scale industry in the field of textiles recycling technology. (FIBRESORT, 2015)

6.7 Properties of the FIBRESBORT machine

The properties of the FIBRESORT shows the improvement in the textile recycling industry. The FIBRESORT is the new developed technology for sorting clothes based on their fibres which means eliminating various textile making processes such as, dyeing, coting, and recycling textile according to their own material and colours. Moreover, in the result of new technology for automatic textiles sorting sustainability in the textile recycling industry. The main advantages of the FIBRESORT have been mentioned below.

- FIBRESORT automatic textiles sorting machine increased the speed of textiles sorting and improvement in processing.
- New NIR application for textiles sorting gives 98% accuracy to detect correct type of fibre.
- Optimized NIR technology for sorting process increased more than 40% of all input to fitful demand for textiles recycling companies.
- FIBRESORT increased the value demand of recycling post-consumer textiles. New technology has created value chain in the textile industry.

Total 40% of FIBERSORT machine meet the requirements for textiles recycling companies.

- New business opportunities and positive feedstock for FIBRESORT.
- Through innovation right kind of textiles materials are available to sort and recycle textiles from post-consumer textiles for Central European countries.
- Business potentials for logistics and textiles recycling companies through FIBRESORT automatic textiles sorting machine. (The Textiles Sorting Project, 2015)

FIBRESORT Functions

- The innovation has been successful with the start of FIBRESORT machine about 5 million of kg textiles has been sorted and graded in high textiles quality.
- The focus was on the establishing new sorting companies for processing post-consumer and non-re-wearable textiles.
- High value textiles recycling from textiles to textiles about 40% of textiles sorted by FIBRESORT are in high grade textiles. The total amount of textiles sorted by FIBRESORT was approximately 2 million Kg in the short scenario.
- The database has been collected by various public sources in the phase of implementing FIBRESORT machine. The public database enabled and promoted upscaling of high value recycling of textiles.
- New supply chain strategies as well market overview for recycled material in the business case.
- In the medium term target for FIBRESORT is set to be 50 million kg/year textiles sorting. (The FIBRESORT project, Circular Economy, 2015)
- Reduce the production of natural fibers on the natural resources and prevent to landfilling.
- Increased the quality of high textiles and sustainable approach to reducing greenhouse gasses.
- Identification of textiles and clothes and automated sorting clothes increased the quality of re-generated fibres.

- Letter of intent, new business opportunities for textiles waste and textiles logistics service providers and post-consumer textiles chains new creativity in the textiles market

7 CONCLUSION

After investigating Dutch state of the art NIR technology and considering theoretical part in this thesis, it is concluded that the use of NIR applications in the field of textile recycling industry has high demand for effective and high valuable textiles recycling. These techniques provide support for various textiles recycling processes with the possibility of efficient NIR application for textiles sorting, which can be used to make high valuable clothes.

Natural fibres production process is not efficiently sustainable, natural resources are not enough to fulfil the future requirement for textiles and clothing industry. However, sustainable approach in textiles recycling is the foremost demand for reducing greenhouse emissions from production process and typical textiles recycling process. Recycling textiles while using various technological and chemical techniques are required. The composition of fibres and textiles should be simple and considered that at the end of textiles life cycle it should be recycled easily.

Textiles4Textiles is a successful project to sort fibres and clothes based on their colours and composition of fibres. The Debut machine for clothes sorting is currently working at the Wieland textiles sorting facility in the Netherlands. Moreover, FIBERSORT is the latest technological development for sorting textiles based on automatic NIR technology. Near-infrared spectroscopy and optical detection technology is a good start towards sustainable textiles recycling, the results from these two projects are very positive. From the findings it seems that the efficiency in the textiles recycling industry is increasing with technology as well as with management system.

Metrohm and Valvan baling systems are the pioneers of the NIR technology for textiles sorting and recycling. Metrohm is still developing technology for sorting textiles while using spectroscopy scanning technology. In addition, Valvan has developed optical detection technology for sorting textiles. These technologies can be further developed. The partners of the Textiles4Textiles and FIBRESORT are in a single value chain, which means they have expertise from various fields. FIBRESORT and textiles circular project are the key elements for sustainable textiles recycling. FIBERSORT and Textiles4Textiles have potential for making business on the base of these technologies.

In FIBRESORT machine there is still room for development, FIBRESORT textiles sorting machine is based on NIR and optical detection technology with high pressurized system to sort clothes piece by piece. For more sustainable and commercial purpose capacity of sorting clothe will be increased. The comparison is made on the basis of RFID and Speech recognition system for textiles sorting and this technology applies to natural fibers and textiles.

It has been investigated that using spectroscopic techniques and optical detection technology have positive effects on environment. Creating value chain and designing supply chain specially for technological and logistics companies have business opportunities in the area of textiles recycling industry.

The textiles sorting and recycling system can be implemented in Finland but Finnish companies in this area should consider either Baltic States or Russia to collect textiles waste and recycling it in Finland. The current system is not so efficient and sustainable for clothing industry. The system will create new jobs in Finland as well as it will help to prevent landfilling and incinerating textiles waste for generating energy, which is current system in the Finnish market. In the Finnish textile market supply chain design is required for Textile waste sorting plant. However, there is a room for further research to investigate about textile recycling system in Finland, empirical research is required to draw final conclusion.

It would be an option for future research to examine the opportunities to adapt the technology also in Finland. It has been found that Sweden is taking step towards textile recycling system in the Sweden. Most of the Swedish companies are agree to collect used textile and send it to the Netherlands for processing, so there will be opportunities for Finland to make recycling plant in Finland. There is potential for the REISKA to identify this need and draw attention to the benefits which will be involved in the textile recycling system in Finland.

8 OUTLOOK

The outcome of this master thesis has increased for further research and recommendations are presented.

For automatic sorting part it will be interesting to analyse on the experimental level in the laboratory how IR techniques work to identify the fibers while using different types of textile's samples. Due to limitations of this thesis experiment has not been used. The combination of Optical detection technology, infrared spectroscopy and optical spectroscopy technology are the technologies which has been used in the Debut machine and the FIBRESORT. It will be interesting to know, how these technologies work together to identify the textiles and sort. There is a room for development in the established technologies for sorting textile based composition of fibre and colour. The present technology which has been used in the FIBRESORT and the Debut Machine is piece by piece, sort textiles on large scale further development is required.

There is a potential for textile collecting and sorting companies in new the technology. Based on FIBRESORT and the Debut machine for automatic textile sorting, there are business opportunities for companies in the area of textile waste management. And what kind of business models can be made for Finland while Circular Economy, Bio economy and Green Economy approach taking into account. How these business models will change the current textile waste management and recycling system in Finland.

For sustainable textiles and clothing industry need to develop more efficient textiles circular system. It has been investigated that production of virgin fibres is not sustainable in anyway. Based on the findings another sustainable textile recycling approach should be taken into account.

At the time of making new clothes and designing textiles, companies need to share their technologies, and other methods of making textiles while considering, material selection, dyeing process, durability and Life Cycle Assessment of textiles.

The manufacturer of fibres and textiles companies need to share their techniques with textile recycling companies and ask for further improvement for sustainable textiles. So manufacturing companies will know what kind of methods and technologies are needed to keep textiles sustainable and at the end of textiles life, textiles are recycled in sustainable way to keep environment safe.

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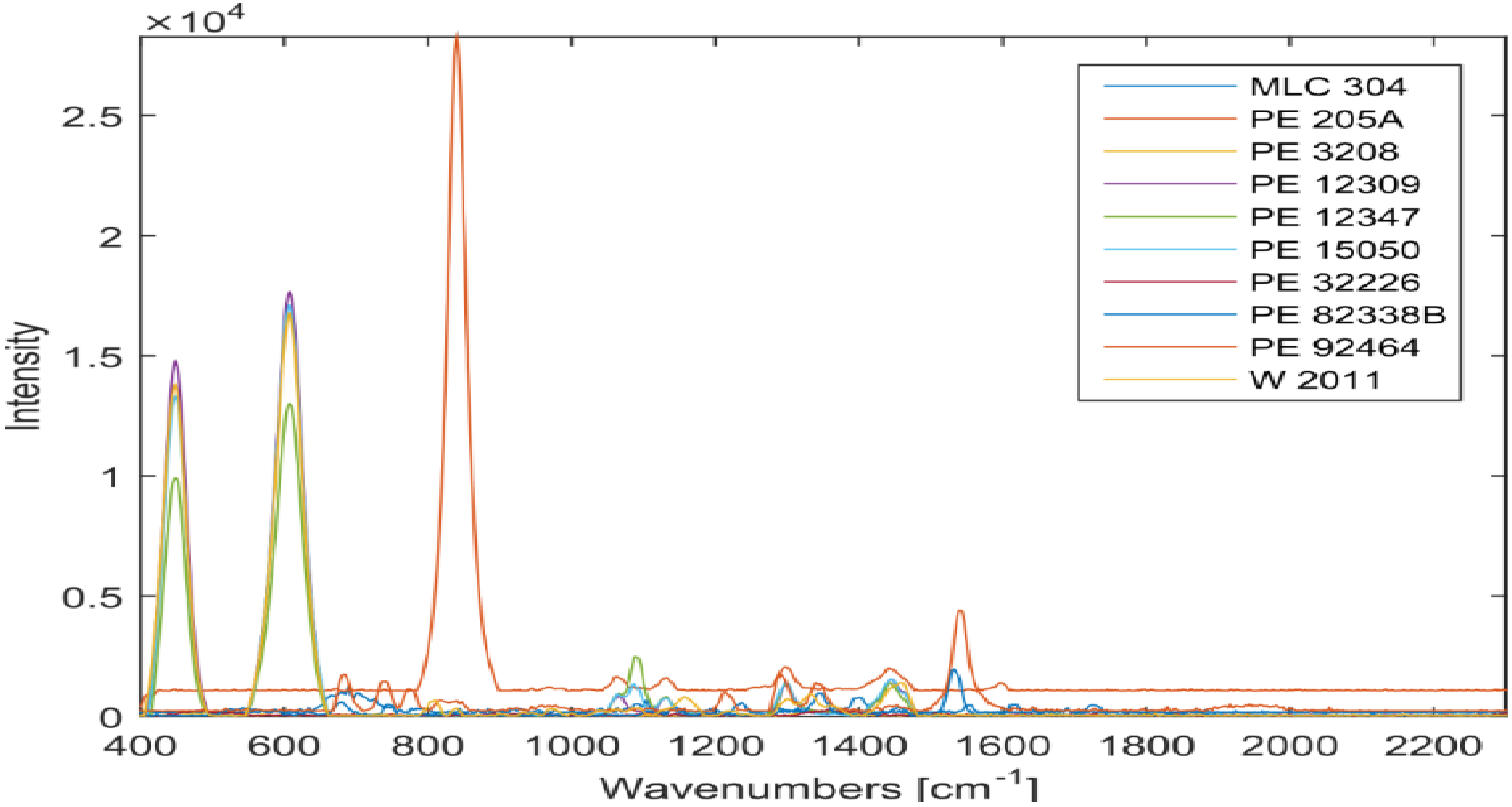
APPENDICES 1

Environmental Comparison of Fiber Types

	Cotton	Organic Cotton	Viscose Rayon	Tencel	Polyester	Recycled polyester	Wool	Cashmere	Alpaca	Nylon
Land impact	Uses prime arable land. Significant pollution from fertilizer and pesticide	Uses prime arable land	Trees grow on marginal land with higher cellulose yields than cotton Some brands use certified wood	Trees grown on marginal land with higher cellulose yields than cotton Wood is certified	None	None	Sheep normally graze on marginal land and cause little damage	Goats can cause significant land damage	Alpaca graze on marginal land and cause little damage	None
Use of non-renewable resources	Used for fertilizers and pesticides	Very little used	Significant chemical use in wood pulp manufacture Significant solvent use in fibre manufacture	Significant chemical use in wood pulp manufacture Solvent used in fibre manufacture is recycled	Made from oil	Made from bottles that were originally made from oil	Very little used—a bit of sheep dip for ticks	Very little	Very little	Made from oil
Water to grow/spin fiber	Very high usage, although some crops are rain fed	Very high usage, although some crops are rain fed	Significant water used in wood pulp and fibre manufacture	Significant water use in wood pulp manufacture	Very low usage	Very low usage	Very low usage	Very low usage	Very low usage	Very low usage
Energy to grow/spin fiber	Low requirement	Low requirement	High energy requirement in wood pulp and fibre manufacture	Less energy in fibre manufacture than viscose	Very high energy requirement	Very high energy requirement	Very low —some greenhouse gases from sheep	Very low —some greenhouse gases from goat	Very low energy requirement	Very high energy requirement
Dyeing and finishing impacts	Very high use of water, energy and chemicals in typical processing	Very high use of water, energy and chemicals in typical processing	Significant, but less water, energy and chemicals use than for cotton	Significant, but less water, energy and chemicals use than for cotton	High temperature dyeing process but shorter process with less chemical use—overall lower impact than cotton	High temperature dyeing process but shorter process with less chemical use—overall lower impact than cotton	Intensive scouring process to remove lanolin plus chemically intensive process to achieve washability	Similar to, but lower impact than wool	Similar to but lower imapct than wool	Similar to Polyester
Other	High pollution loading from dyeing Untreated effluent causes major damage.	High pollution loading from dyeing Untreated effluent causes major damage	Very significant pollution from some wood pulp and viscose factories	Much less pollution than from viscose factories but wood pulp the same		Two methods of recycling —one depo-lymerisation / repolymerisa-tion and the other a lower impact, simple melting pro-cess that yields slightly inferior fibre	Recycled wool of only slightly lower quality than virgin wool is available from Italian industry	Cashmere goats are raised in very fragile areas	Alpaca are raised in less fragile terrain	Recycled nylon is becoming available

Fibre selection: Understanding the impact of different fibres is the first step in designing environmentally responsible appeals. (CLEAN by Design). Natural resources defence council 2012.

Appendix 2



Spectral measurement technique is used to analyse fibre the composition of textile fibres. The mode is autonomous in this spectral analysis and Mira Cal software has been used.

Identification of various polymer master batches. (Raman spectroscopy Application note RS-7) Metrohm applications for fibres identification.