Analysis of Pulper rejects samples by manual sorting

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Foreword

I have written this thesis as part of my Bachelor of Applied Science degree at the Arcada University of Applied Sciences, Finland. In this thesis, recycling is the subject matter. There are several interesting things written about this topic as it relates to the recycling of liquid paperboard packaging and pulper rejection.

It is with great pleasure that I thank Allah Almighty and my family and a few people here for their endless support. It has been really helpful to have guidance, reviews, and recommendations from Mirja Andersson and Faizan Asad. My special thanks go out to Faizan Asad who guided me every step of the way while working and writing. Additionally, I would like to thank Annika Annika Översti for the FTIR spectrum scans.

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Abstract:
The main objective of this thesis is an analysis of the recycling of liquid paperboard and the process of pulper rejects. Recycling is the process that converts waste materials into new materials and objects and recovers energy. And recycling becomes a key component of the modern world. However, with the third component of the "Reduce, Reuse, and Recycle" waste hierarchy (www.wtert.net, n.d.). Recyclable materials contain glass, paper, cardboard, metal, plastic, tires, textiles, batteries, electronics, etc.
Liquid paperboard has multilayer polymer-coated layers of aluminum foil. LPB (liquid paperboard) beverage cartons are multilayer polymer-coated paperboards that are used to make shelf-stable milk and juice products. Those cartons have an LDPE (low-density polyethylene) outer layer that provides that moisture barrier protecting the printing ink layer applied to the paperboard.
The experiment was performed in the laboratories at Arcada University of Applied Sciences.

Keywords:	Recycling, liquid packaging board, pulper reject
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Table: Sorted materials, percentage, polymer type, and FTIR result

1. INTRODUCTION

1.1. Background

Recycling is the process that collects and processed materials into new products. On the other hand, it can be called the process of converting waste materials into new materials and objects. Recycling is the process that converts waste materials into reusable objects, prevents waste of useful materials, reduces the consumption of fresh raw materials, air pollution, water pollution, etc.

Recycling becomes a key component of the modern world. However, with the third component of the "Reduce, Reuse, and Recycle" waste hierarchy (www.wtert.net, n.d.).

Fig1: three components Recycling (Reduce, Reuse and Recycle)

Reduce, Reuse, Recycle is also referred to as the 'Three Rs' of recycling (www.reducere-userecycle.co.uk, n.d.). It means reducing the amount of waste we produce, reusing items as much as possible before replacing them, and recycling the items (Solar Schools, n.d.).

There are many types of waste materials that can be recycled:

Metals (Aluminum foil, Aluminum cans, Steel, tin cans, etc.) that use in everyday life are often recyclable. As it's a very flexible material, it takes less energy than to produce a new item, it is remanufactured repeatedly without losing its purity.

Paper and Cardboard (Corrugated cardboard, Magazines, newspapers, etc.) can reuse to remanufacture new papers. Glass (Flint glass, Amber glass, Emerald glass).

Plastics (PET, HDPE, PVC, PE, LDPE, PP, other) recycling is the process of recovering waste plastic materials into useful products. some kinds of plastic can be recycled about 2–3 times before their quality decreases.

There are two types of recycling: internal and external:

Internal: Internal recycling is the reuse of material in the manufacturing process. And it's common in the metals industry.

External: External recycling is the repossessing of materials that have been worn out or been old. Like the collection of old newspapers and magazines for remanufacturing into new paper products.

1.2. Objectives:

To research Liquid paperboard recycling.

To find out the percentage of different plastic types in pulper reject.

1.3. Methodology:

This thesis is written based on the literature review and the experimental part. The analysis and results of the literature review are based on research studies on recycling and liquid paperboard package. Several articles and journals were referred from databases such as Wikipedia, ScienceDirect, ResearchGate, and many more to write this thesis. In this thesis, the experimental part was done by pulper reject samples. Pulper rejects are the waste product of production. It contains valuable materials. Pulper reject materials consist of metal, plastic film, string, wooden parts, and small plastic parts.

2. LITERATURE REVIEW

2.1. History of recycling

Recycling started thousands of years ago but its popularity has been its ups and downs since the idea was sprouted. Here are some historical dates for recycling:

500 B.C: Athens organizes the first municipal rubbish dump programs and makes laws for its citizens to deposit their waste there.

1031: Japan starts the first-time reuse of wastepaper. All the documents and paper are recycled and re-pulped into new paper.

1690: In Philadelphia, the paper manufacturing process is introduced and named Rittenhouse Mill. They made the paper from fiber derived from recycled cotton and linen rags.

1900'S: Recycling supporters and reuse programs accepted the phrase "waste as Wealth" (Busch Systems Resource Center, 2016)

1940: Europe and the United States started using nylon, rubber, used batteries, and various scrap metals for recycling purposes to help the war effort.

1964: All aluminum cans can be used as raw materials for making new cans.

1965 To 1970: The Mobius Loop has presented the "Reduce, Reuse, Recycle" symbol.

1972: The first recycling mill has built-in Conshohocken, Pennsylvania (Busch Systems Resource Center, 2016).

In Finland, the system for returning beverage containers started in the 1950s, and nowadays almost every bottle and can is recycled.

2.2 Steps of recycling

There are four steps of recycling:

Step 1: Collection: In this step, recyclable is Material collected from various locations. After the collection, the recyclable materials are sent to a materials recovery facility.

Step 2: Processing: After collection recycling materials are sent to a Material Recovery Facility (MRF) for sorting, cleaning, and processing into materials used in manufacturing.

Step 3: Manufacturing: In this step manufactured products become new products.

Step 4: Purchasing Recycled Products: The last step is purchasing recycled products. Recycled products are as good as in price and quality as products made from virgin materials. And buying recycled products creates long-term markets for recyclable materials (Recyclespot.org, 2020).

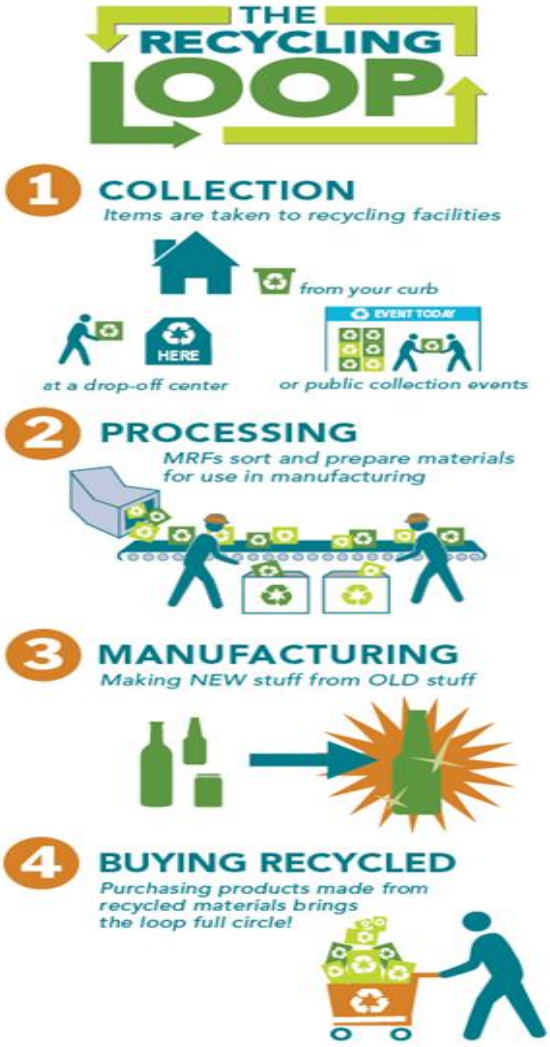

Fig 2: steps of recycling (Recyclespot.org, 2020)

2.3 LPB (Liquid paper board package)

Paperboard is commonly used for packaging food and beverage products including juices, milk, and cereal products. Paperboard packaging appears in several categories. One is solid bleached sulfate (SBS) paperboard, it contains 80% virgin bleached wood pulp. And

used for most gable-leading and sterilized drink packages. The second one is Coated unbleached kraft paperboard (CUK), which contains 80% virgin unbleached wood pulp. And used for non-gable top beverage cartons and frozen food packages. (www.sciencedirect.com, n.d.)

Liquid packaging board (LPB) is an important part of storing and transporting liquid food. And It's an integral part of storing and transporting liquid food. Because of their composition and qualities at all steps of the recycling process, LPB differs from conventional paperboard packaging materials (www.papcel.cz, n.d.). Some applications of liquid packaging board:

Juices

Milk, yogurt, dairy products

Soups, tomato products, desserts, oils, etc.

Fig 3: Different types of Liquid Packaging Board (Reports, 2018)

Liquid Packaging Boards is a multi-layer paperboard with a high barrier coating, high rigidity, and robust wet sizing (Wikipedia, 2019), like Aluminum, and plastic. Where only the virgin paper fibers are used. The liquid packaging board has up to six plies and is formed on a multi-ply paper machine with an online coating. The most common one is the use of three plies and that's basis weight is about 300 g/m2. The base is made of bleached or unbleached chemical pulp. It gives more bulk and stiffness. The top ply is made of bleached chemical pulp (Khazaria, 2020). The barrier coating can be applied on

both sides. For barrier protection and heating, an aluminum foil layer is used. Liquid packages are normally heat-coated.

There are two package types of Liquid packaging:

brick and gable-top cartons.

2.3.1 Types of LPB

There are two types of liquid paperboard packages:

2.3.1.1 long-life (foil-lined) cartons

Long-life cartons are generally brick-shaped and contain long-life products such as long-life milk. They don’t store in the fridge and are found on shelves. The bricks are made from paperboard with a thin layer of plastic on the carton's exterior and interior and a very thin aluminum foil layer on the interior to keep the products fresh for a long time. And quantity is 75 % paperboard, around 20 % polyethylene (LDPE), and some 5 % aluminum. Figure 4 shows a layer of long-life cartons, which includes,

Polyethylene: a barrier to moisture

Paperboard: for stiffness

Polyethylene: an adhesion layer

Aluminum: a barrier to oxygen

Polyethylene: an adhesion layer

Polyethylene: seals in liquid food contents

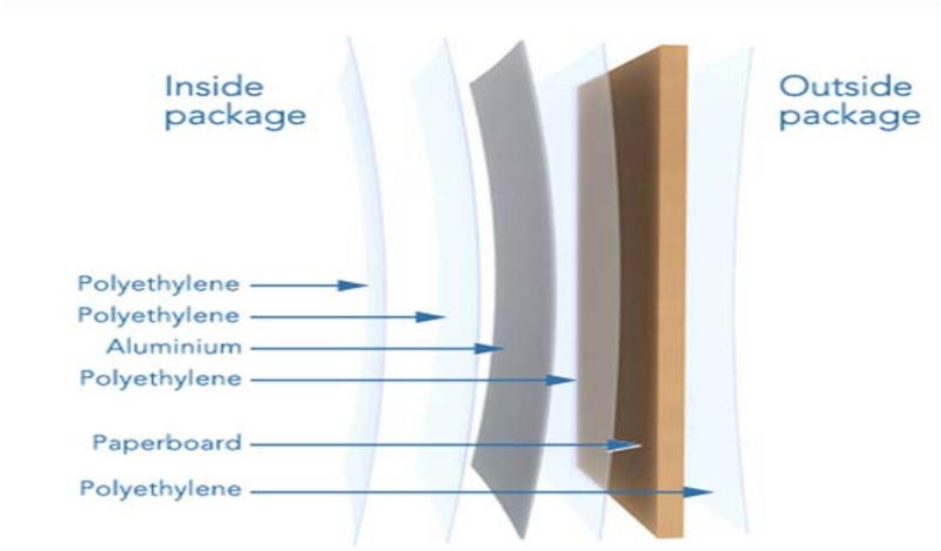

Fig 4: Long-life LPB cartons layer (Everyday Recycler, 2020)

2.3.1.2 Fresh cartons

Fresh cartons are mostly found in fridges, and it has three to four layers. These cartons are made from a layer of paperboard and very thin plastic, where 80 % paperboard and 20 % LDPE. A layer of fresh cartons is shown in figure 5 and contains, Polyethylene

Cardboard

Polyethylene

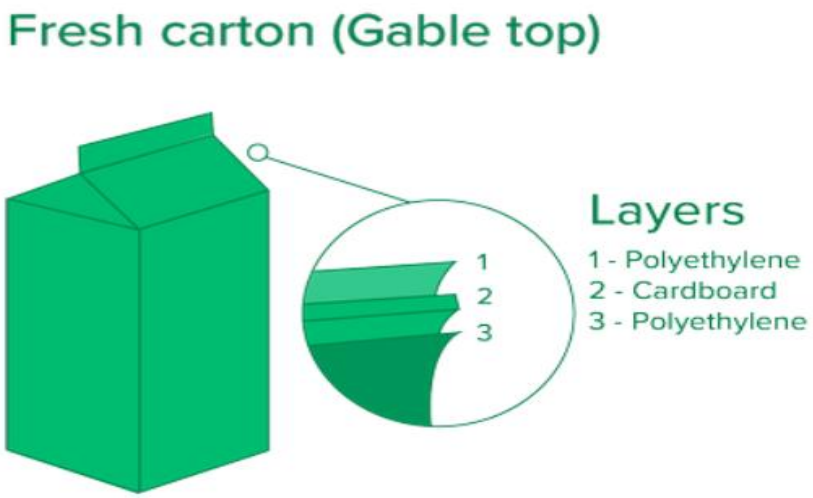

Fig 5: Fresh LPB cartons layers (RNY, 2019)

2.3.2 Recycling Option of LPB

Recycling options has categorized into four options:

a Primary Recycling

In primary recycling, also known as loop recycling, the recycled materials are reprocessed back into their original products with the same quality as before. But it directly doesn't convert into the original product.

b Secondary

In this process, materials are processed and used in applications that don't require virgin material properties, and it's the most common recycling option for aseptic cartons. The paper fibers are separated from the PolyAl (polyethylene & aluminum) and combined into paper products. One more secondary recycling process is converting the shredded cartons into construction materials.

c Tertiary

Tertiary recycling is breaking a product into its chemical building blocks and recycled into various products.

d Quaternary

It works with incineration with energy recovery. Mechanical, chemical, and thermal processes are used to separate the polyethylene and aluminum from the remaining paper fibers that have been recovered.

2.3.3: Steps of LPB Recycling

Before recycling need to collect the food and beverage cartons. Because every recycled item helps to preserve our planet's natural resources (Carton Council, n.d.). When recycled, cartons go transformed into new paper products as well as eco-friendly building materials.

Here is the step of the processing LPB:

Step 1: Empty food or liquid cartons.

Step 2: keep the carton in the recycling bin without crushing it.

Step 3: Take the recycling to the curb where it's collected.

Step 4: Next step is to go to the sorting center.

Step 5: At the recycling sorting center, cartons are separated from other recyclable materials manually or using infrared technology, and by robots using artificial intelligence.

Step 6: In this step, there are two possible ways of recycling; **one way:** PAPERMILL: Cartons are sent to a paper mill.

Second way: BUILDING MATERIALS: As an alternative to the paper mill, cartons can also use for building materials

Step 7: Papermill: Cartons are going into a large machine known as a "Hydrapulper". It's a blender that use to break the cartons into two parts:

paper and plastic/aluminum. Paper pulp is used to make paper products such as paper towels, tissue, office papers, etc. Plastic and aluminum are used to produce ceiling tiles, wallboard, or even energy to fuel the paper mill.

Step 8: Finally, from the recycled cartons paper pulp Becomes new paper products like toilet paper, paper towels, or eco-friendly building materials like roof cover boards (Carton Council, n.d.).

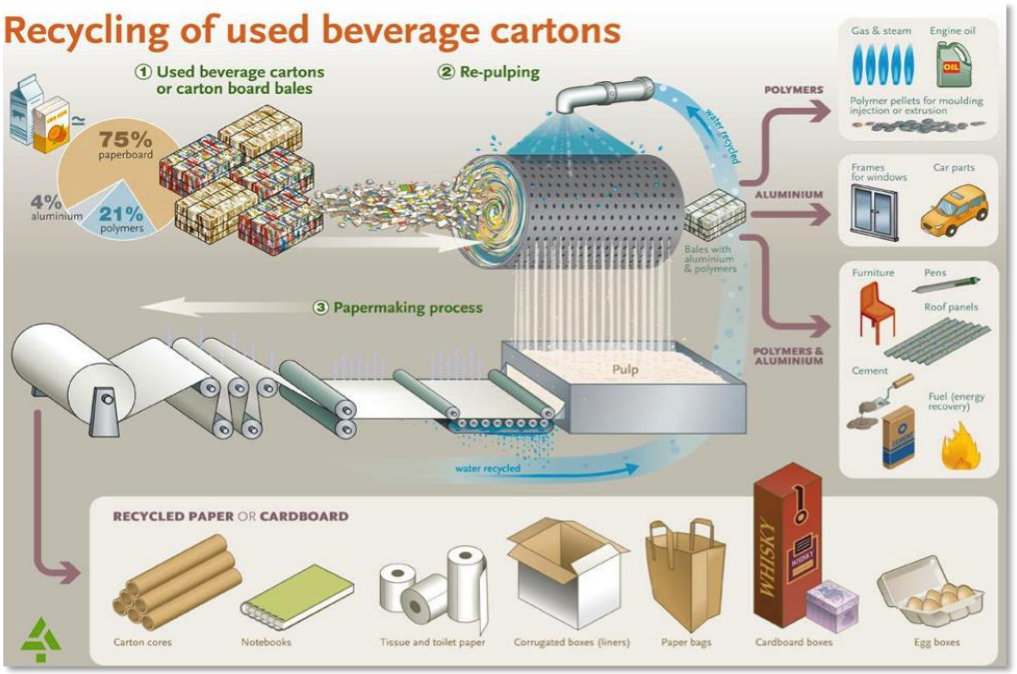

Fig 6: Recycling steps of used liquid paperboard packaing (Kupfer, n.d.)

2.4 Pulper Reject:

Pulp and paper factories produce different types of solid wastes during the paper recycling process. Rejects, green liquor sludge, dregs, and lime mud, as well as wastewater treatment and chemical flocculation sludge, are all produced by pulp mills (Ouadi et al., 2018). And Paper mills produce wastes like rejects, deinking sludge, and secondary or biological sludge (Ouadi et al., 2018). Rejects, deinking sludge, primary sludge, and intermediate or biological sludge are all waste products produced by paper mills. Collect fiber lumps, plastics, metals, glass, and other impurities are rejected by the paper mill. Metals, glass, as well as other contaminants, were separated from rejects before sorting. Dewatering rejects are simple, and they can be disposed of incineration or in landfills (Ouadi et al., 2018).

Pulper rejects are a type of reject material that has a high-water content and is not suitable for recycling. Before being sent to landfills or incinerator sites, shredder rejects are dewatered (Ouadi et al., 2018).

Pulper braids, also known as rejects, are a byproduct of the paper manufacturing process. Pulpers are very important for recovering paper stock. In pulper production, they have up to 50 % metal wires. And Plastic film, twine, wooden bits, and little plastic parts are among the other components (WEIMA Maschinenbau, n.d.). Nowadays paper is one of the best raw materials and its recycling rates are more than 70%. The recycled fibers and wastepaper are usually delivered as pressed bales. These bales of wastepaper are fed into the primary pulper. The plastic films, textile remains, binding wires, and similar items are fed to the plant at the same time as the wastepaper. They appear as a form of pulper rags and loose rejects. Pulper rags are a very challenging mechanical compound of metallic and non-metallic components. Rope lengths of up to 15 m and diameters up to 800 mm. (AG, n.d.).

Fig 7: Pulper rejects (www.waste-outlet.com, n.d.)

2.4.1 Advantages and Benefits of Pulper Reject recycling

As a result of recycling pulper rejects, transforms waste into valuable secondary raw materials. This reduces the number of rejected wastes. Reduces operating costs and improves efficiency. Pulper reject recycling reduces greenhouse gas emissions (CO2) and saves energy. It cleans the output fractions.

2.4.2 Process of Pulper reject recycling

Process of recycling pulper rejects into raw material, the steps are receiving a pulper reject that is defined by plastic, aluminum, water, and impurities from the separating process. then moisture and removing, softening, and compacting the pulper reject, obtaining a recycled raw material, and fed the materials into thermoplastic transformation machine and acquire a new product (mentioned and Lucke, n.d.).

Steps of reject system

Shredding: In this step, the shredder cuts the lengths of the pulper rag. Before starting the process, large particle needs to reduce, and a screen selects the perfect size of the materials.

Metal separation: A magnetic over-belt separator is used to separate ferrous, and an eddy current separator is used to separate nonferrous metals. Before starting the process,

the large pieces of ferrous metal need to be removed. Small metal pieces and non-ferrous metals are separated after shredding.

Metal detection: large particles cause malfunctions and damage to machinery, to be prevented the causes needs to use for metal detection. If a large metal piece causes a change in an electromagnetic field and the metal pieces are detected it sends a signal to the conveying system control unit.

Compacting: In this step dewaters are rough and the fiber is mechanically to the maximum dryness

Separation of unwanted components: Next remove material containing PVC. Plastic materials like, (PP, PE, PVC, etc.) are detected and classified. And on the end-use of the raw material, one or several detected components are removed. For this separation, it requires dryness and particle size.

Drying: Waste heat for sludge and reject drying. Pre-dewatered material is distributed in a permeable belt. Hot air is blown on the rejected material. The low-temperature level and long residence time for drying reject material.

Sand and heavy-particle sedimentation: This step is for removing sand, glass, and other heavy rejects by gravity. Low stability rejects with a high content of heavy particles come from cleaning and pulper detrashing.

Sewage water screening: This system protects the treatment system.

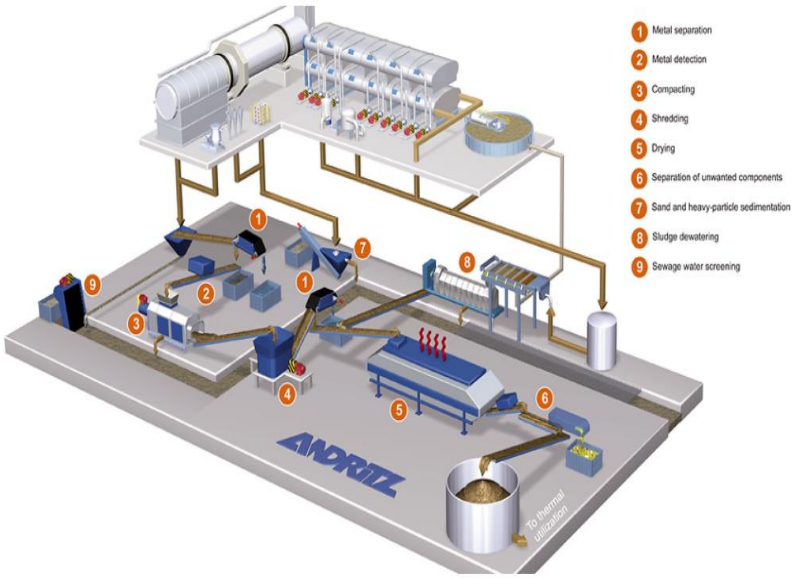

Fig 8: Pulper Reject recycling system based on drum pulping (AG, n.d.)

Figure 9 shows there are some pulper rejects before starting the treatment pulper reject recycling

Fig 9: Pulper reject (Tecnofer, n.d.)

In figure 10 it shows after the pulper rejects treatment materials become pulp

Fig10: After treatment of pulper reject (Pulp) (Tecnofer, n.d.)

In figure 11(a, b, c) shows the new product found from the pulper reject.

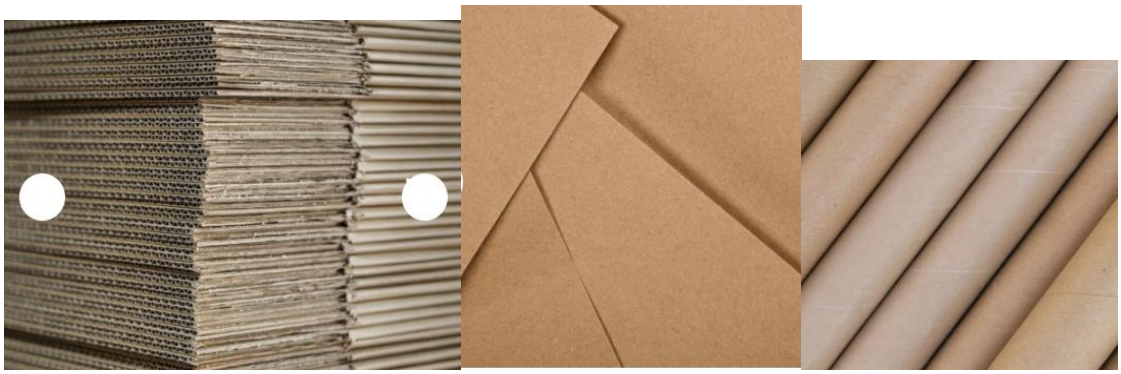

Fig 11 (a, b, c): New Product made from pulper reject (Tecnofer, n.d.)

3 EXPERIMENT AND RESULT

3.1 Material

The purpose of this experiment is to sort pulper reject. LUT University provided two bags of pulper rejects for the experiment. These are mixed with various types of materials. One bag of pulper reject was used for sorting, after being measured, it was 7kg or 7000g. Having the pulper sorted was necessary to determine the amount of plastic or aluminum in the sample, as well as the type of polymer found, and if there was any potential for recycling them. Figure 12 shows pulper rejects resulting from the LUT.

Fig 12: Pulper reject (at Arcada)

3.1.1 Safety Equipment

In spite of the fact that no safety equipment was necessary for this experiment, LAB rules mandated the use of safety equipment.

Lab Coat

Gloves

Safety goggles

3.1.2 Method

The experiment was carried out in the Arcada lab using pulper reject. The work involved sorting pulper reject. In the process of sorting the rejected materials, several types of materials were found, including aluminum, plastic, bottle caps, and glasses. A mixed material of aluminum and plastic was difficult to separate [FA1] Sorted materials also contained different types of polymers. Some of them were mixed with aluminum and plastic. The plastic also has different types -- polypropylene bottle caps, transparent plastic, dense plastic. Found one PCB (Printed Circuit Board) that also contains plastic. Cloth was mixed with paper. Some expandable polymers were also found.

3.2 Result

After completing the manual sorting of the pulper reject samples, samples were measured and calculated. Measurement was done by floor and bench scales. One table is shown below. It shows the materials that were found with figures and the percentage after the calculation. The FTIR spectrum identifies the type of polymers in each category. FTIR scans can be found in Appendix.

Table 1. Sorted materials, weight percentage, polymer type, and FTIR result

Materials	Percentage (wt%)	Picture	Polymer identification through FTIR scans	Materials in kilo
Aluminum	30.03		NA	2241g

Plastic bottle caps (polypropylene)	18.31		Polyethylene, Polypropylene	1282g
Transparent Plastic thin films	8.01		Polyethylene (PE), ABS	561g
Mixed plastic and Aluminum	3.02		NA	211.6g
Paper	0.39		Polypropylene (PP), Polypropylene (PP)	27.6g
PCB (polycarbonate)	0.06		Unknown	4.4g
Cloth	0.33		Rayon, Polyethylene (PE), Polypropylene (PP)	23.4g
Wood	0.27		Unknown	18.7g
Glass	0.15		Polystyrene (PS)	10.3g

Metal	0.67		NA	47.2g
Expandable polymer	0.24		Styrofoam	16.8g
Dense plastic parts	0.22		Unknown	15.7g
Color plastic	2.11		Nylon, Polyethylene, polypropylene	147.7g
Rubber	0.45		Styrofoam, Polyethylene (PE)	31.2g

Unsorted materials	35.71		Unknown	2500g

The percentages of the different categories of pulper reject can be better explained with the help of a pie chart. The pie chart, it's showing how much plastic has been found from the manual sorting of pulper reject. Among all percentages, unsorted materials are the highest percentage 35.7%. Those are the material that has tiny plastic, aluminium, and paper and combined with other material, for this those material wasn't possible to sort manually. The second highest amount found is aluminium, it's 30,3%. From the pie chart, plastic bottle caps are 18.3% of the amount which is the third-highest number. Paper, glass, and PCB board is the lowest in percentage almost 0,1%.

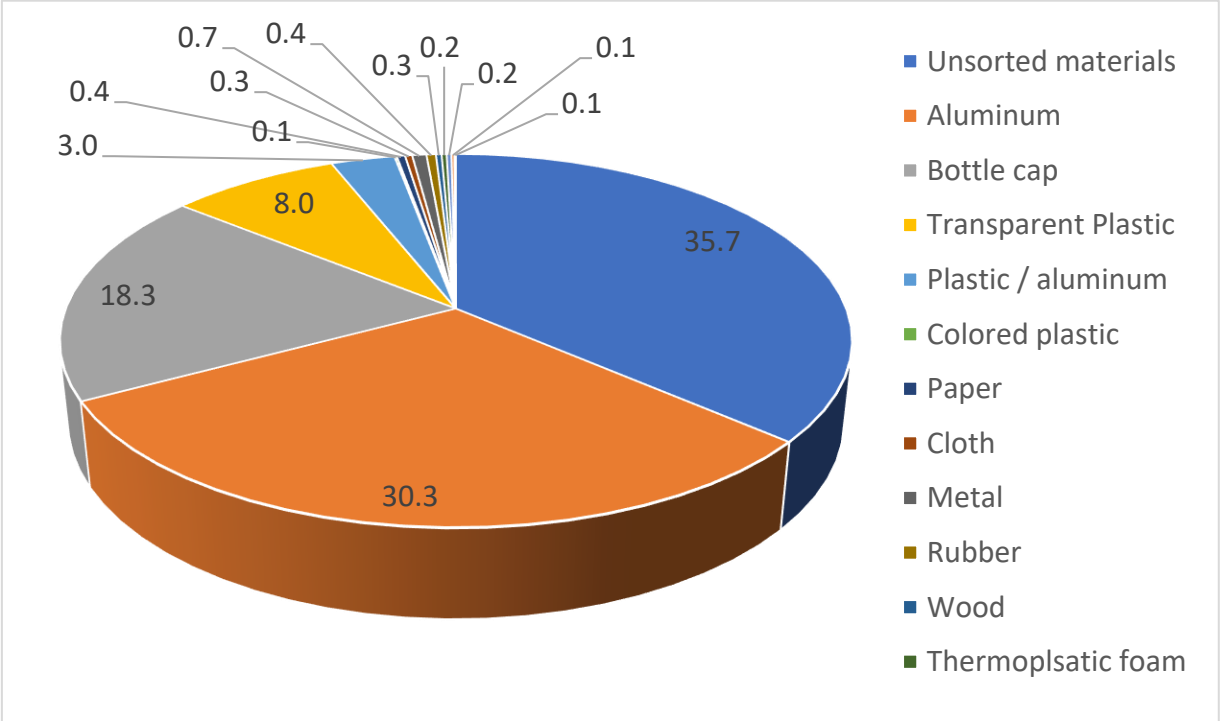

Fig 29: Pie chart for sorted materials with the percentage

The pie chart is showing the plastic found from the sorting of pulper reject. The amount of plastic from pulper reject after manual sorting is around ~ 29,3%. But there is more plastic in the unsorted category. Six types of plastic were found in the sorting, bottle caps,

transparent thin plastic, coloured plastics, etc. Among all plastic bottle caps the highest amount found, the percentage was 18.314%. and the lowest amount found was dense plastic 0,224%.

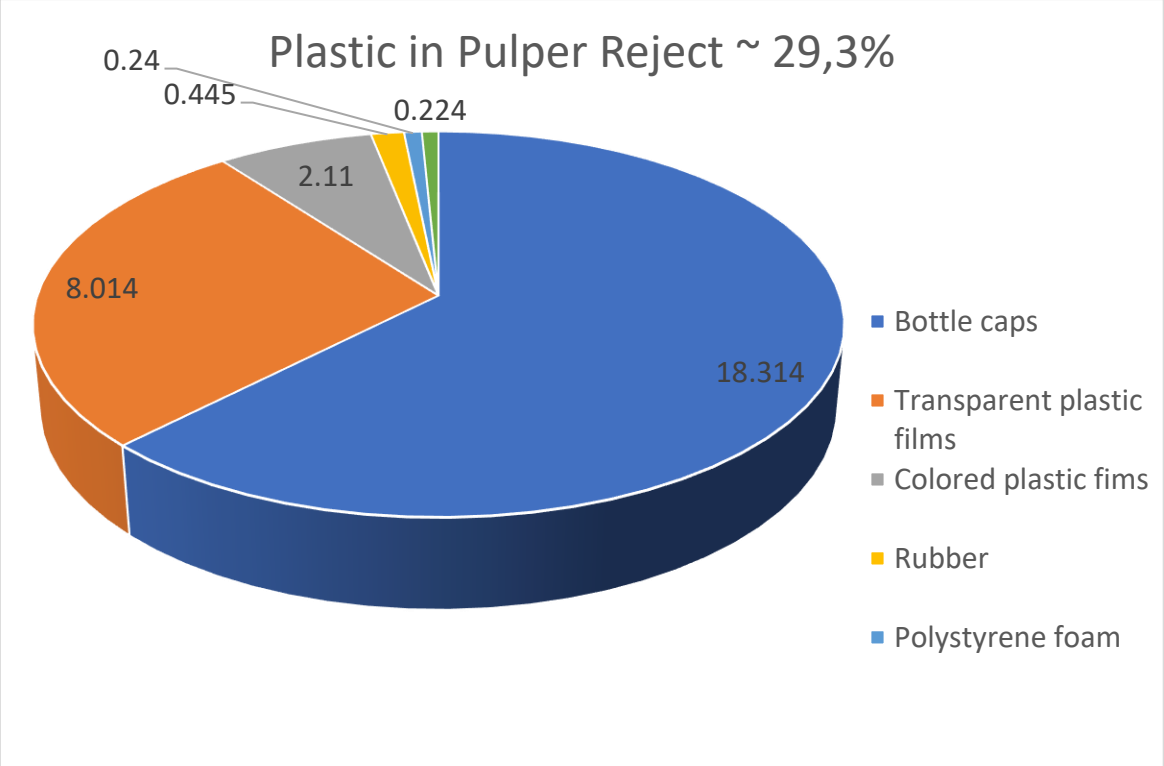

Fig 29: plastic in pulper reject

4 Conclusion

Pulper reject samples were sorted in the Arcada LAB. Different types of materials were found in the experiment. Most of them were Plastic and Aluminum. Various kinds of plastic are also found e.g. polypropylene, polycarbonate, polyethylene, ABS, Nylon, PVC, Polyester etc. transparent thin plastic, dense plastic, and expandable polymers. Other materials were wood, cloth, paper, and metal, rubber. In samples, there were some materials that were not possible to sort. Sorted samples were applied in FTIR. FTIR spectroscopy scanning was done by research assistant Annika Översti at Arcada UAS.

FTIR (Fourier-transform infrared spectroscopy) is a technique that obtains an infrared spectrum of solids, fluid, or gas's absorption and emission, it acquires high-resolution spectral data over a large spectral range (Wikipedia Contributors, 2019). FTIR is the dominant technique in infrared spectroscopy for a variety of reasons (Merck, 2021). It does not damage the sample. It is much faster than previous systems and is much more efficient and accurate. Organic synthesis, polymer science, petrochemical engineering, pharmaceutical business, and food analysis are all areas where FTIR spectroscopy is applied (Merck, 2021).

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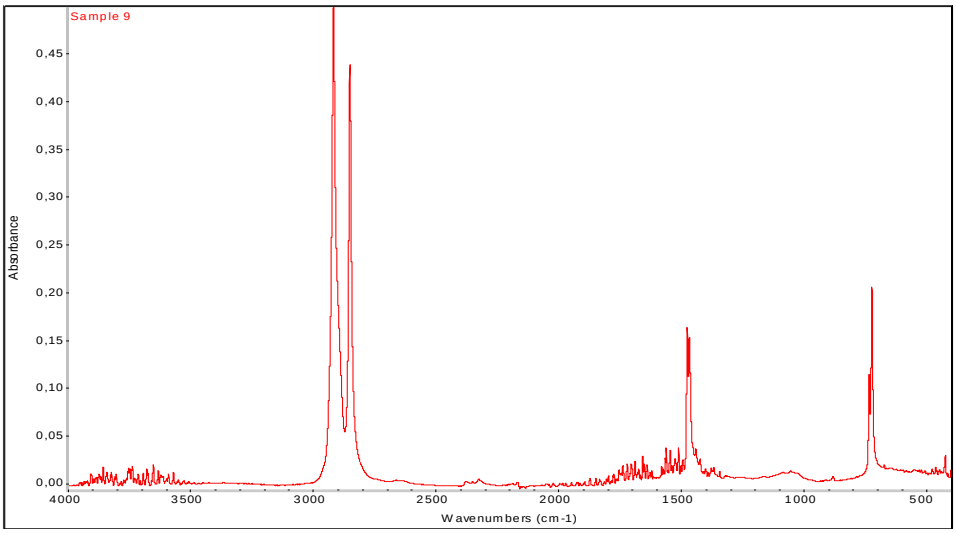
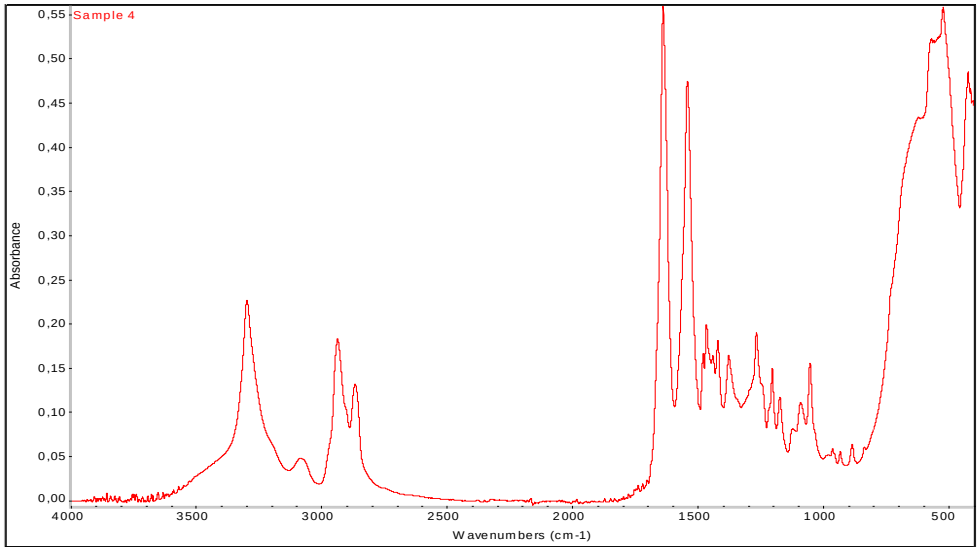
APPENDICES

Appendix 1

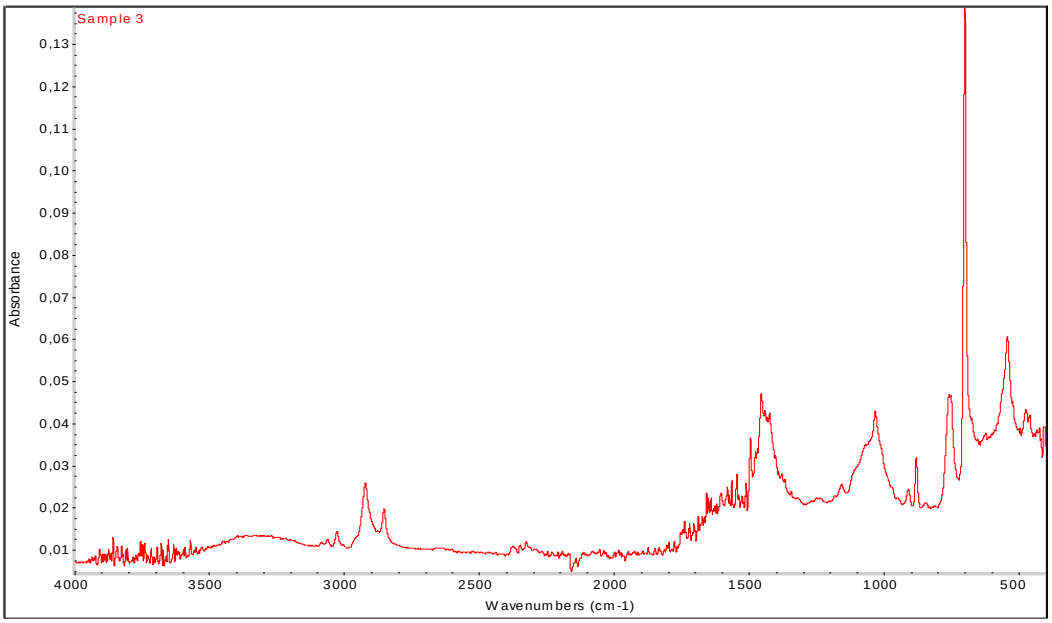
FTIR scans of the bottle cap, it matches 96,43% Polyethylene (PE)



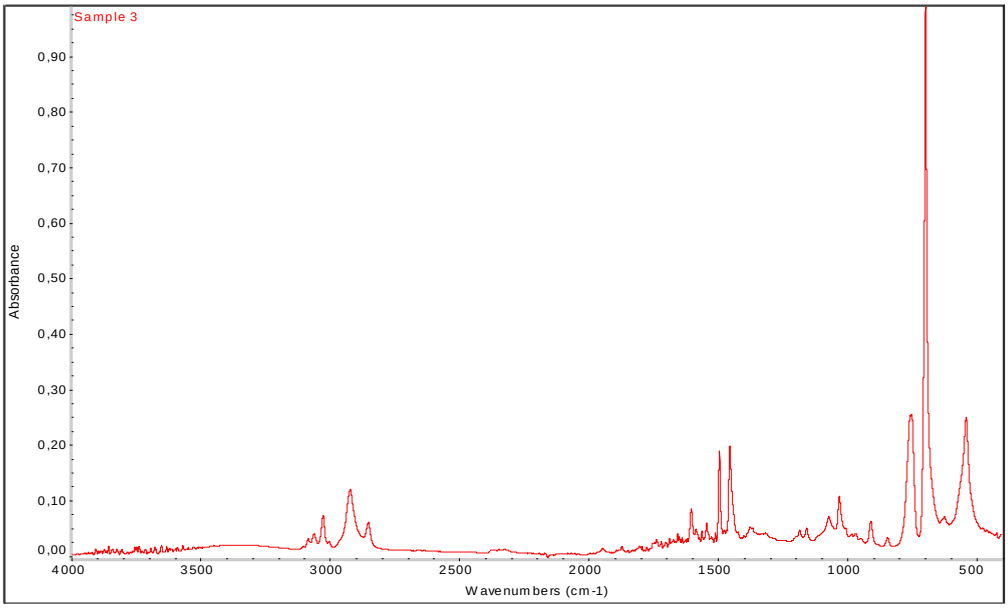
Colored plastic was scanned in FTIR spectrum, matches nylon 88,72%.



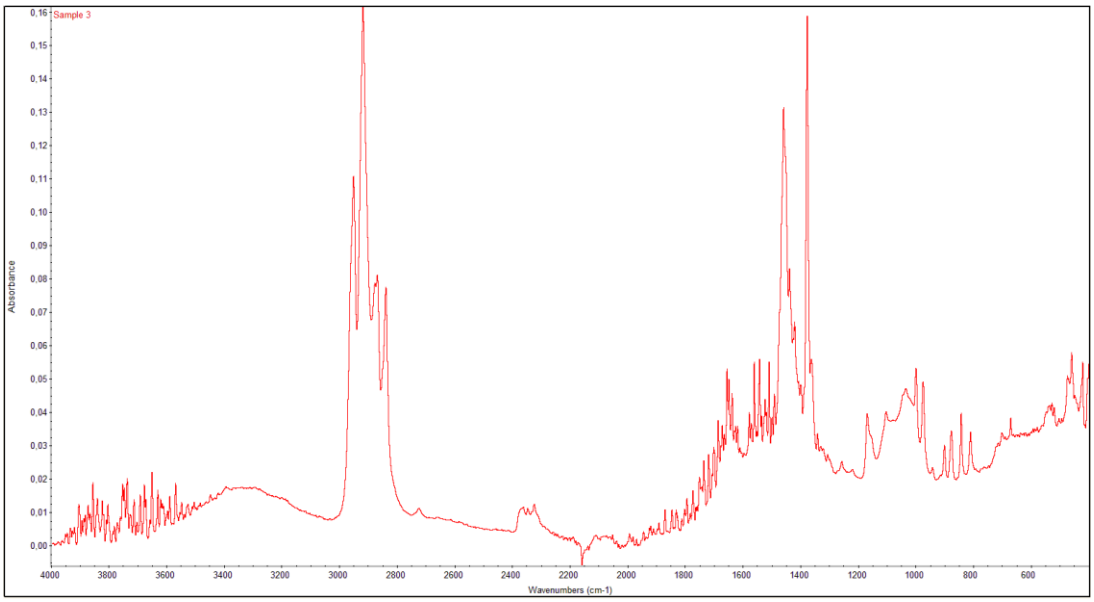
FTIR scans of expandable polymer and it matches 96,16% with styrofoam.



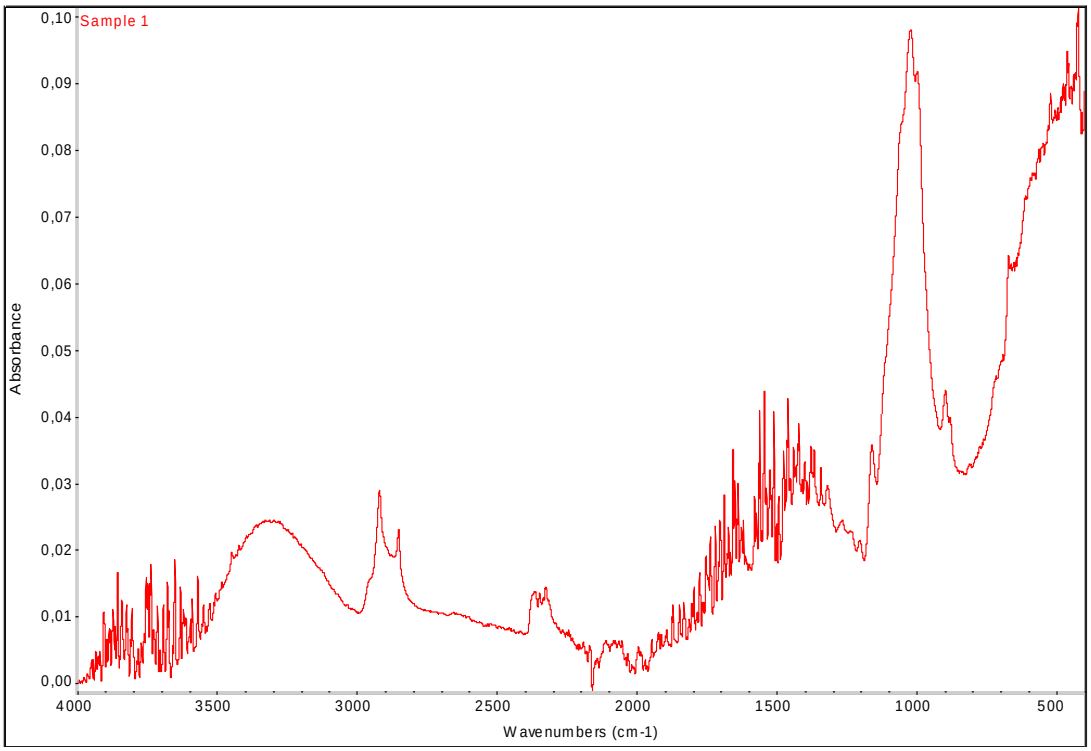
FTIR scans of glass, 93,38% matches Polystyrene (PS)



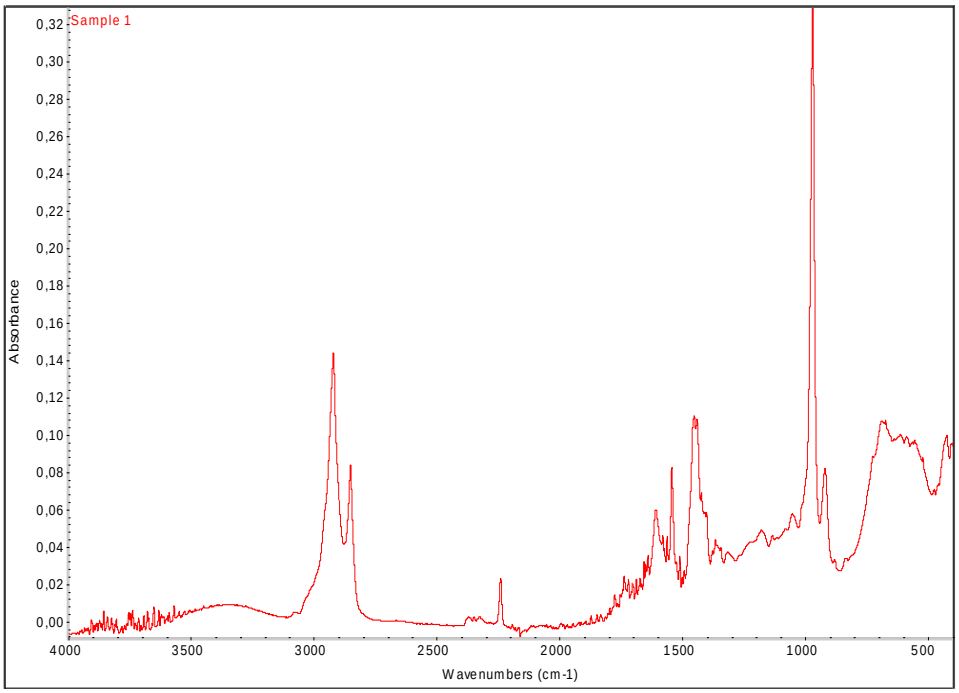
FTIR scans of cloth match Polypropylene (PP) at 82,90%.



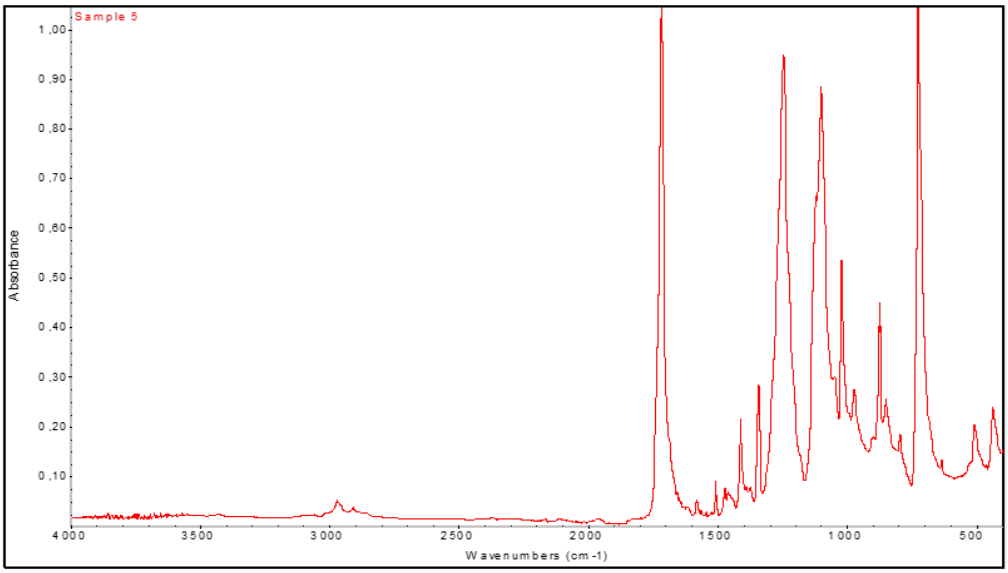
FTIR scan of cloth matches 71% of rayon

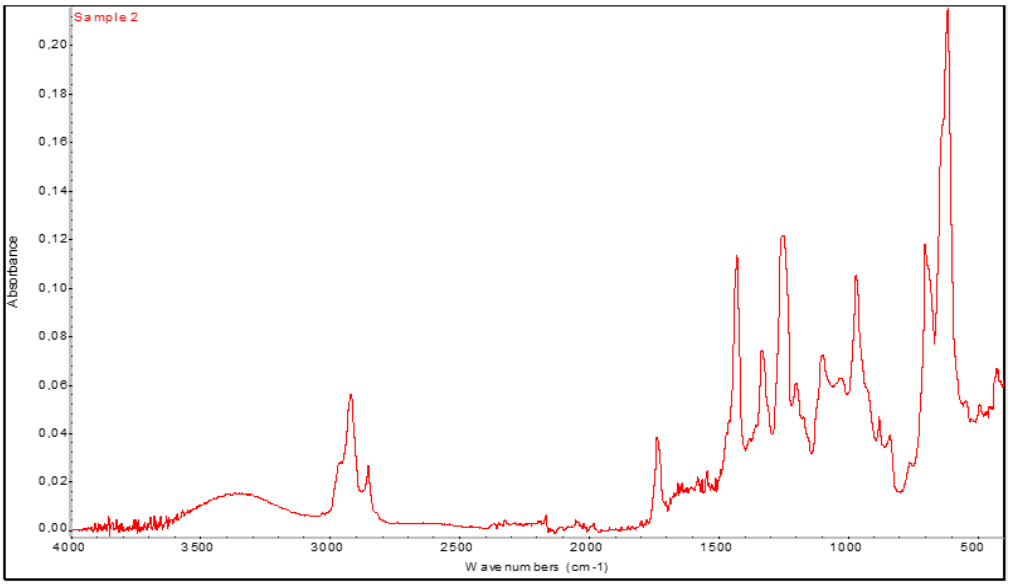


FRIT scan of transparent thin plastic matches ABS 96,0%



FTIR scans of plastic Polyester 93,1% match and Poly(Vinyl chloride) 90,7% match




Sample 2
Absorbance
0,20
0,18
0,16
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
4000
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)