Abstract

The UK produces 3 million tonnes of plastic waste each year, of which 85% is landfilled, 8% is incinerated and only 7% recycled. Recycling just one plastic bottle saves enough energy to power a 60W light bulb for six hours. Our local East Riding of Yorkshire Council is trying to reduce the amount of waste by recycling different types of waste. However, not all plastics can be recycled by the council currently. The aim of this project is to develop a device that can distinguish between the different types of plastic which can be and cannot be recycled with the help of an infrared spectrometer. Different types of plastics (eg. PVC, PET, HDPE) have different forms of spectra. Materials can be identified by comparing their spectra to reference spectra. The aim here is to make a cheap and simple device to do this in the home. This could be in a form of a box containing an infrared source that will illuminate the plastic to be tested, perhaps through a set of filters of plastics that can be recycled. If the light passes through both filter and plastic under test onto a detector this will collect the radiation and pass a signal to an electronic circuit to indicate its suitability for recycling.

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Table Of Contents

Contents

Abstract 1

Acknowledgement 2

Table Of Contents 3

List Of Figures And Tables 6

1.0 Objectives 8

2.0 Introduction To Recycling 9

2.1 Definition Of Recycling 9

2.2 The 3Rs' – Reduce, Reuse and Recycle 10

2.3 What Is Recycling? 11

2.4 Why Is Recycling Important? 12

2.5 Why Recycle? 13

2.6 Environmental Benefits of Recycling 14

2.7 Energy Efficiency 16

2.8 Recycling Symbols 17

2.8.1 The Recycle Mark 17

2.8.2 The new packaging symbols 17

2.8.3 The Green Dot 18

2.8.4 Glass 18

2.8.5 Aluminium 19

2.8.6 Steel 19

2.8.7 The Mobius Loop 19

2.8.8 The Tidyman 20

2.9 How To Recycle? 21

3.0 Introduction to Project 22

Electro-Optical Method Of Distinguishing Recyclable Plastics 22

3.1 Introduction to Plastics 22

3.2 Project Literature Review 24
3.2.1 Abstract........ 24
3.2.2 Introduction 25
3.3.3 Conclusion 27
3.4 Public Awareness Around The University Of Hull 28
3.5 Environmental Pollution: The Harmful Effect Of Plastic Materials........ 30
3.6 Plastic Types and Symbols 31
3.6.1 Polyethylene Terephthalate (PETE or PET) 31
3.6.2 High Density Polyethylene (HDPE)........ 32
3.6.3 Polyvinyl Chloride (PVC)........ 33
3.6.4 Low Density Polyethylene (LDPE) 34
3.6.5 Polypropylene (PP) 35
3.6.6 Polystyrene (PS) 36
3.6.7 Other........ 37
3.7 Why Recycle Plastics? 38
3.8 Identification of different types of plastics........ 39
4.0 Background Research 40
4.1 A two-colour near-infrared sensor for sorting recycled plastic waste (DM Scott) 40
4.1.1 Near-infrared absorbance spectra........ 41
4.1.2 Simulation of a two-colour spectrometer........ 44
4.1.3 Hardware Implementation 45
4.2 Automated sorting of plastics for recycling (Edward A Bruno)........ 48
4.2.1 Macrosorting 48
4.2.1.1 Spectroscopy........ 48
4.2.1.2 X-RAYS........ 49
4.2.1.3 Laser-aided identification 49
4.2.2 Microsorting 50
4.2.2.1 Sink Float Systems 50
5.0 Progress Work 52
5.1 Fourier Transform Infrared Spectroscopy (FTIR) 52
5.2 The Sample Analysis Process 53
5.3 Why Infrared Spectroscopy? 54

5.4 Obtaining spectra for plastic samples using the FTIR 55
5.5 Effect of plastic thickness 62
5.6 Effect of contamination on the plastic 64
5.7 Transmitters 65
5.8 Detectors 66
5.9 Working theory of the transmitter and detector 68
5.9.1 Transmitter 68
5.9.2 Detector 68
5.9.3 Detector Circuit 69
5.9.4 Detector Circuit Schematic 70
6.0 Working Theory Of The Detector Circuit 71
6.1 Experiments With Different Plastics Materials 77
6.1.1 Polyethylene Terephthalate (PET) 77
6.1.2 Polystyrene (PS) 78
6.1.3 High Density Polyethylene (HDPE) 79
6.1.4 Polypropylene (PP) 80
6.1.5 Plastic bags 80
6.2 Alternative results 81
7.0 Discussion 83
7.1 Factors which may affect the plastic sorting process 88
7.2 Other technologies used for plastic sorting 89
8.0 Hardware Design 91
9.0 Budget 92
10.0 Gantt Chart 93
11.0 Conclusion 94
12.0 Future Work 95
13.0 References 96
14.0 Appendix 98
15.0 Archive CD 102

List Of Figures And Tables

Figures

Figure 1: The Waste Hierachy 10
Figure 2: The Recycle Mark 17
Figure 3: The new packaging symbol 17
Figure 4: The Green Dot Symbol 18
Figure 5: Recycling symbol for glass materials 18
Figure 6: Recycling symbol for aluminium materials 19
Figure 7: Recycling symbol for steel materials 19
Figure 8 (left to right): The Mobius Loop Symbol, The Mobius Loop Symbol with Percentage 19
Figure 9: The Tidyman Symbol 20
Figure 10: Polymer Structures 23
Figure 11: Recycling bins found around the University 28
Figure 12: Absorbance spectrum of PET 42
Figure 13: Absorbance spectrum of PVC 42
Figure 14: The hardware implementation (D M Scott) 45
Figure 15: Proposed plastic recycling schematic with high-pressure separations (Atland et al. 1995) 51
Figure 16: Example of how to obtain sample spectra using FTIR 52
Figure 17: How an FTIR works 53
Figure 18: Resulting graph from Equation (4) 56
Figure 19: Spectra of all 5 different filters 58
Figure 20: Spectra for 1 layer of different types of plastic 59
Figure 21: Transmittance of each plastic and filter 4 60
Figure 22: Relative transmittance of each plastic using Filter 4 61
Figure 23: Transmittance of 1, 2 and 3 layers of PET 62
Figure 24: Effect of grease on plastic spectrum 64
Figure 25: Suitable detectors graph 66
Figure 26: Response of the pyroelectric detector 67
Figure 27: Basic circuit to measure detector responsitivity 69
Figure 28: Detector circuit for measurement 70
Figure 29: Circuit for a basic operational amplifier comparator circuit 71
Figure 30: Detector circuit (Figure 28) 73
Figure 31: Detector circuit (Figure 28) 74
Figure 32: Results from Test 1 75
Figure 33: Results from Test 2 75
Figure 34: Noise which affects the circuit 76

Figure 35: Water bottle PET sample 77
Figure 36: Results from the PET sample 77
Figure 37: White Cup PS sample 78
Figure 38: Results from PS sample 78
Figure 39: Milk bottle HDPE sample 79
Figure 40: Results from HDPE sample 79
Figure 41: Black box PP sample 80
Figure 42: Plastic bag sample 80
Figure 43: Spectra for different plastics (recyclable and non-recyclable) 83
Figure 44: Transmittance of each plastic and filter spectra 85
Figure 45: Cut off wavelength of the detector 85
Figure 46: Signal vs wavenumber graph 86
Figure 47: Draft Model Design 91

Tables

Table 1: Average time taken for each example to biodegrade on earth 12
Table 2: Energy saved by recycling versus using raw materials 16
Table 3: Oil saved by recycling one ton of material versus using one ton of raw material 16
Table 4: Recycling guide for different materials 21
Table 5: Simple test of identifying plastics 39
Table 6: Polymer density ranges (Atland et al. 1995) 50
Table 7: Results from Test 3 81
Table 8: Results from Test 4 81
Table 9: Results from Test 5 82
Table 10: Comparison between plastic technologies (Michael B. Biddle) 90
Table 11: Project Budget 92
Table 12: Gantt Chart 93

1.0 Objectives

The recycling of plastics from packaging, particularly bottles, has grown significantly during the last ten years for most industrial countries. While the recycling industry has experienced significant market challenges due to price fluctuations, the recovery of polyethylene terepthalate (PET) and high-density polyethylene (HDPE) is still being carried out in numerous large scale operations throughout the world. The growth of bottle recycling has been facilitated by the development of processing technologies that increase product purities and reduce operational costs.

Therefore, to encourage the benefits of recycling, we should also play a part to recycle plastics. As being part of the environment, we can all make our own important contributions to long term environmental improvements through dealing with our rubbish in a much more sustainable way and through this, divert more rubbish away from unacceptable landfill sites. This project is a step to encourage recycling between the public, and also to make the process much easier.

East Riding of Yorkshire Council residents have set their council to achieve a recycling and composting rate of 45%.

Thus, the objectives for this project are as follows:

1. To develop a device that is capable of distinguishing plastic materials.
2. To ease the process of separating recyclable plastics from the non-recyclable plastics.
3. To encourage the benefits of recycling.
4. To help nature and its environment.
5. To find a suitable method to work with the project.
6. To learn about the spectrometer and its uses that can be helpful.
7. To develop our imagination and put into practice what we have learned.
8. To learn project planning and organization.

2.0 Introduction To Recycling

2.1 Definition Of Recycling

Recycling has been a common practice for most of human history, it has been around as long as there have been humans to do it. Recycling involves processing used materials (waste) into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduces air pollution and water pollution, and lower greenhouse gas emissions. Recycling is a key component of modern waste reduction.

Recycling has been one of the most basic human responses to living in the world, and learning to live, survive and indeed thrive by using, and then reusing the resources that we can find around us. From the early days of mankind, when our ancestors were hunter-gatherers, evidence from this time shows the resourcefulness of early weaponry. For example, using flints, both for fire and as tips for spears, and then becoming more sophisticated and using the parts of the animal that can't be eaten, the bones, as tools to help them hunt.

Recyclable materials include many kinds of glass, paper, metal, plastic, textiles, and electronics. However, the composting or other reuse of biodegradable waste, such as food waste or garden waste, is not typically considered recycling. Materials to be recycled are usually brought to collaborating collection centers, and it will be sorted, cleaned and reprocessed into new materials bound for manufacturing.

There are two types of resources, renewable and nonrenewable. Renewable resources include material that we can make more of including fast growing trees. These trees can be planted and grown at a sustainable rate. Nonrenewable resources are materials that do not regenerate, such as petroleum products including oil, gasoline, plastics etc. Therefore, all relevant resources used need to be conserved, focusing on the nonrenewable resources.

2.2 The 3Rs' – Reduce, Reuse and Recycle

There are three great ways in which everyone in society can eliminate waste and protect the environment, which is to reduce, reuse and recycle. The rubbish that we as a society are producing threatens to engulf us, and that could eventually pollute our mother earth.

The Waste Hierarchy can be used to determine the most effective way to reduce the impact of waste towards the environment. The Figure 1 below indicates the importance of reducing, reusing and recycling in order to divert waste away from landfill.

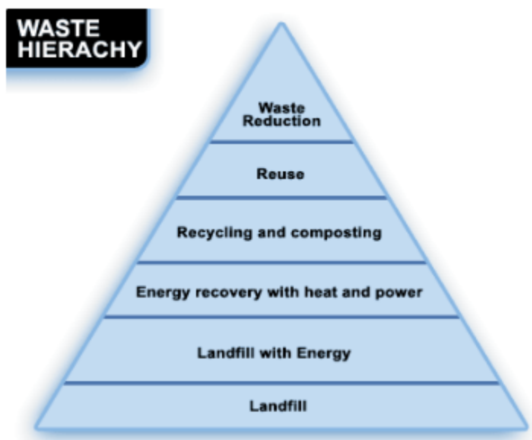


Figure 1: The Waste Hierachy

Reduce – Reducing waste saves both materials and energy, and removes the need and expense of disposal. For example, we can reduce waste by not buying disposable items, looking for alternatives with less packaging, avoiding the use of unnecessary shopping bags and putting a stop to junk mail. These options will assist in reducing the waste produced, and we may also save a little money out from it.

Reuse – Reusing reduces the need to buy new items and so saves resources. Taking an example from choosing reusable containers rather than disposable ones, buying milk from the local milkman will encourage people to reuse the containers they have rather than adding another container into their inventory. Other examples may include donating old clothes to charity shops and bringing along extra bags for shopping rather than adding the use of plastic bags.

Recycle – Recycling saves valuable raw materials, and it also cuts down on waste disposal costs. Items for recycling are collected and sent to the re-processors who then break down and separate the recyclables into their base materials. Once these base materials are purified, they can be used to make new products, eg. plastic bottles can be made into fleeces.

The 3Rs assist in leading the society to a sustainable future, we need to adopt ways of living that will continue to support our way of life for generations to come.

2.3 What Is Recycling?

Recycling is what we do with the objects we use in our daily lives, it is the process of collecting materials that are often considered trash and remanufacturing them into new products that can be resold and used again. Recycling is ultimately a creative act that involves thought and dedication to extend the life and usefulness of something that seems to have no more purpose once it has been used for its initial purpose. Common objects that are often used only once are plastic containers, glass bottles, and newspapers. Most, if not all things can be recycled somehow. Therefore, our perception of our lifestyles and the ease of disposal have to be changed so we could manage to use creative and technical abilities to recycle everything we dispose of. Other than that, we can save nature from pollution.

2.4 Why Is Recycling Important?

Recycling is more important than ever because just throwing away trash in a landfill or digging a hole and burying it is not a solution to the waste problem. Most natural trash items like food can break down and decompose in a matter of time, leaving no trace of it in the environment. However, man-made products like glass, plastic bags and aluminum cans may take months or years to break down.

The Table 1 below will show the averages for how long it takes for a certain product to biodegrade in the earth:

Examples	Time
Plastic soda bottles	1 million years
Glass	1 million years
Aluminum cans	50 to 200 years
Paper	1 to 5 months
Disposable diaper	500 years
Batteries	100 years

Table 1: Average time taken for each example to biodegrade on earth

2.5 Why Recycle?

- Recycling Conserves Resources

  When we recycle, used materials are converted into new products, reducing the need to consume natural resources. If used materials are not recycled, new products are made by extracting fresh, raw material from the earth, through mining and forestry. Recycling helps conserve important raw materials and protects natural habitats for the future.

- Recycling saves energy

  Using recycled materials in the manufacturing process uses considerably less energy than that required for producing new products from raw materials including all other associated costs such as transportation, packaging and manpower etc. Plus there are extra energy savings because more energy is required to extract, refine, transport and process raw materials ready for industry compared with providing industry ready materials.

- Recycling helps protect the environment

  Recycling reduces the need for extracting, mining, quarrying, logging, refining and processing raw materials all of which create substantial air and water pollution. As recycling saves energy it also reduces greenhouse gas emissions, which helps to tackle climate change. According to research, the current UK recycling work is estimated to save more than 18 million tonnes of CO2 a year which is equivalent to taking 5 million cars off the road.

- Recycling reduces landfill

  When we recycle, recyclable materials are reprocessed into new products, and as a result the amount of rubbish sent to landfill sites reduces. There are over 1,500 landfill sites in the UK, and in 2001, these sites produces a quarter of UK's emissions of methane which happens to be a powerful greenhouse gas.

2.6 Environmental Benefits of Recycling

The environmental benefits of recycling also save our communities money. Economics and environment are both priorities in this industry. While we are still using material, refining it, and making new items with it there is less raw material being used and therefore fewer steps. There are many benefits from recycling considering all parts of the process. For starters, well-run recycling programs cost less to operate than waste collection, landfilling and incineration. This way, many steps could be eliminated including the mining process associated with raw materials and much of the transportation. There is energy savings, savings of resources, a reduction of greenhouse gas emissions, less landfill space used, and reduction of water and air pollution along with several economic benefits. The more people recycle, the cheaper it gets.

As there are many benefits from recycling, the society acts to carry out many recycling programs to encourage recycling among the public. Communities have many options available to make their programs more cost-effective, including maximizing their recycling rates, implementing pay-as-you-throw programs, and including incentives in waste management contracts that encourage disposal companies to recycle more and dispose of less.

From an economic standpoint, recycling makes money from the sale of material to offset the cost to run a recycling facility. There are several types of recycling centers including government run and commercial businesses. Commercial recycling businesses must make money to continue providing service. Many municipalities have the potential to make money if more recycling product is brought in. In the event of a government run recycling facility generates money it can be placed into surplus account for the governmental general fund. This surplus account can take pressures off to raise taxes, eventually. The cost to operate a landfill is significantly higher in comparison to the cost of operating a recycling facility for municipalities.

Employment concerns are always an economic priority in any community. Recycling provides more jobs than any other solid waste program. Public sector investment in local recycling programs pays great dividends by creating private sector jobs. For every job collecting recyclables, there are 26 jobs in processing the materials and manufacturing them into new products. According to some research, landfilling 10,000 tons of waste creates 6 jobs, while recycling the same waste creates 36 jobs. Recycling creates six jobs for every one job created in the waste management and disposal industries. Regardless of the employment opportunities, thousands of companies have saved a huge amount of money through their voluntary recycling programs. Recycling fuels the economy by providing jobs, decreasing energy needs and usage, and finally bringing revenue to the community.

Every bit of recycling make a difference, it takes 95% less energy to recycle aluminum than it does to make it from raw materials. Making recycled steel saves 60%, recycled newspaper 40%, recycled plastics 70%, and recycled glass 40%. These savings far outweigh the energy created by-products of incineration and landfilling.

Manufacturing with recycled materials, with very few exceptions, saves energy and water and produces less air and water pollution than manufacturing with virgin materials. Every ton of paper that is recycled saves 17 trees. The energy saved when one glass bottle is recycled is enough to light a light bulb for 4 hours. Some other benefits would include reducing greenhouse gas emissions, conserve natural resources such as timber, water and minerals. Recycling prevents habitat destruction, loss of biodiversity, and soil erosion associated with logging and mining. Lastly, recycling reduces the need for mining for raw materials. As mining is the world's most deadly occupation, 40 mine workers are killed on the job each day on average, and many more are injured.

2.7 Energy Efficiency

As mentioned above, recycling saves energy which is used to produce new materials from raw materials. The following Table 2 and Table 3 shows the energy requirement considering the processing of each material, transportation demands, mining demands, and the entire recycling path versus the energy taken to create a brand new material out of raw materials.

Material	Energy Saved by Recycling (%)
Glass	30% energy savings
Cardboard	24% energy savings
Newspaper and office paper	34% - 60% energy savings
Steel (tin cans)	74% energy savings
Plastic	88% energy savings
Aluminum	95% energy savings

Table 2: Energy saved by recycling versus using raw materials

Material	Barrels of oil saved	Gallons of oil saved
Aluminum	40	1,663
Cardboard	1.1	46
Newspaper	1.7	71
Office Paper	9	380
Steel	1.8	76
Plastic	16.3	685

Table 3: Oil saved by recycling one ton of material versus using one ton of raw material

Petroleum is one of the nonrenewable resources on earth, it does not regenerate. The consumption of oil accounts for a large percentage of the world's energy consumption. According to research, from 2010 to 2020, the maximum of oil production will be reached. Therefore, it is encouraged to save and reuse oil in every way including household usage, industries usage etc.

2.8 Recycling Symbols

In this time of recycling with the emphasis on recycling waste rather than simply dumping it, it is worth having an understanding of what the symbols on the packaging of the items actually mean.

Numerous labels appear on packaging to advice consumers and promote environmental claims. To ensure these claims are accurate, a set of international standards have been developed known as the Green Claims Code, and is issued by the British Standards Institute.

A guide is shown below to help understand all the symbols that can be found on packaging.

2.8.1 The Recycle Mark

recycle

Figure 2: The Recycle Mark

The Recycle Mark is a call for action, it does not necessarily mean that it could be recycled or collected locally. However, it is used to encourage users to try to reuse or recycle the material as much as possible. There would be a certain assumption that it is not finalized as a 100% fully recyclable material.

2.8.2 The new packaging symbols

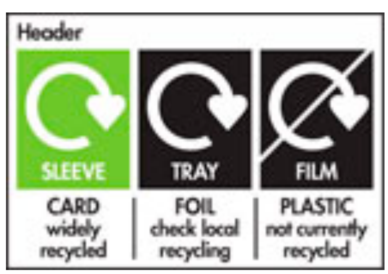


Figure 3: The new packaging symbol

Sometimes, there would probably be different parts to a single item which some may be recycled and some may not be recycled. As it can be seen from the Figure 3 above, it shows different parts to a single item which shows the possibility of its recyclable potentials. Thus, "Widely Recycled" means 65% of people have access to recycling facilities for these items. "Check locally" means 15%-65% of people have access to recycling facilities for these items and "Not recycled" means less than 15% of people have access to recycling facilities for these items. These symbols are a guide to how widely different packaging items are recycled, it would be necessary to follow the advice of the local recycling authority.

2.8.3 The Green Dot

Figure 4: The Green Dot Symbol

The Green Dot (Der Grǔne Punkt in German) is the license symbol of a European network of industry-funded systems for recycling the packaging materials of consumer goods. The logo is trademark protected worldwide. It does not necessarily mean that the packaging can be recycled. In simple terms, the system encourages manufacturers to cut down on packing as this saves them the cost of license fees. It signifies that the produces has made a contribution towards the recycling of the packaging.

2.8.4 Glass

Figure 5: Recycling symbol for glass materials

When it comes to recycling glass, a selection of recycling bins used for collecting green, clear, brown, and miscellaneous glass bottles and containers can be found at local council refuge sites.

2.8.5 Aluminium

Figure 6: Recycling symbol for aluminium materials

Most of the gas drinks and alcohol cans we use today are made from aluminium and it takes less energy to recycle 20 aluminium cans than it does to produce one brand new one.

2.8.6 Steel

Figure 7: Recycling symbol for steel materials

This symbol shows a container being attracted by a magnet, this symbolizes that the container is steel and therefore can be attracted by a magnet unlike aluminium.

2.8.7 The Mobius Loop

Figure 8 (left to right): The Mobius Loop Symbol, The Mobius Loop Symbol with Percentage

The Mobius Loop – a circle in conventional sense. The purpose of this symbol is to inform the purchaser of such products that the packaging can be fully recycled. The Figure 8 on the right side is slightly different with the figure in the middle of the loop, this figure is a percentage that relates to the amount of packaging that can be recycled. This means the figure was 25%, then 25% of the packaging can be recycled while the rest would need to be disposed of.

2.8.8 The Tidyman

Figure 9: The Tidyman Symbol

The symbol shows the Tidyman figure is placing a paper in a waste basket. This symbol is the uniform symbol for the 'Keep Britain Tidy' campaign and is also used on street sings to signify the illegality of dropping litter. This is not related to recycling, but it is a reminder to be a good citizen.

2.9 How To Recycle?

Materials	Recyclable Items	How To Prepare Them
Plastic Bottles (#1 and #2)	• Milk jugs • Shampoo Bottles • Drink/Water Bottles • Laundry Detergent Bottles • Cleaner Bottles	• Rinse and clean the bottles • Remove lids
Clear & Brown Glass	• Food and Beverages Containers • Clean and Brown Jars and Bottles	• Rinse and clean the glass • Remove lids
Aluminium & Tin	• Aluminium Foil, Pie Tins, Can & Food Trays • Food and Beverages Containers • Empty Aerosol Cans	• Rinse and clean well • Empty aerosol cans
Cardboard & Boxboard	• Corrugated Cardboard • Boxboard – Cereal Cracker Box Material • Brown Paper Bags • Shoe Boxes • Dry Food Boxes	• Flatten • Large pieces on top of bin/Deliver to depot • Remove tape, liners or and other cellophane etc.
Newspapers, Magazines & Catalogues	• Newspaper Print • Magazines • Glossy Catalogues • Glossy Flyers & Brochures	• Collect and stack together accordingly
Office Paper	• White & Colored Paper • Office Paper • Ruled Paper • Sticky Notes • Envelopes	• Remove any paper clips • Place into clear bag • Distinguish acccordingly

Table 4: Recycling guide for different materials

3.0 Introduction to Project

Electro-Optical Method Of Distinguishing Recyclable Plastics

Now that we know how important recycling is in our daily lives, it makes a difference if we all take part and contribute to making the world a better place. As my research shows, there are many types of materials that can be recycled including plastics, glass, aluminium etc. However, this project only focuses its attention towards plastic recycling. Unfortunately, recycling of plastics has proven to be a difficult process. The biggest problem is that it is difficult to automate the sorting of plastic wastes, making it labor intensive. New processes of mechanical sorting are being developed to increase capacity and efficiency of plastic recycling. For these reasons, there is a need for a simple, rugged sensor that can distinguish between the different types of plastics which shall be explained further along with the report.

3.1 Introduction to Plastics

Plastic is one of the most widely used products in the world. It is used to package consumer products, to charge our purchases with credit cards, plastic bags to carry food and drink, to build toys and even make clothings. There are over 10,000 different kinds of plastic in the world, and it is so versatile and can be mixed with so many other elements that its uses are limitless.

Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and or to reduce costs. Plastic materials can be formed into shapes by one of a variety of processes, such as extrusion, moulding, casting or spinning. Modern plastics possess a number of extremely desirable characteristics such as high strength to weigh ratio, excellent thermal properties, electrical insulation and others. These polymers are made of a series of repeating units known as monomers. The structure and degree of polymerisation of a given polymer determine its characteristics. Linear polymers (single chain) and branched polymers (linear with side chains) are thermoplastic, they soften when heated. Cross-linked polymers (two or more chains joined by side chains) are thermosetting, they harden when heated.

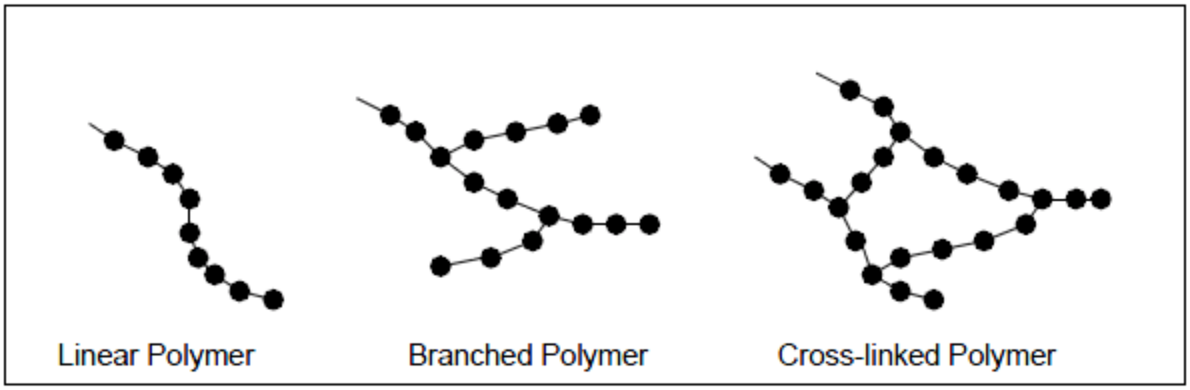


Figure 10: Polymer Structures

Thermoplastics make up 80% of the plastics produced today. Examples of thermoplastics include:

- High Density Polyethylene (HDPE)
- Low Density Polyethylene (LDPE)
- Polyethylene Terephthalate (PET)
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl Chloride (PVC)

Due to the fact plastics are formed by chains of monomers strongly attached, it degrades very slowly and it does not lead to the complete breakdown of plastics. Therefore, it may a very long time, we're looking at the next few thousand years, till plastics can finally breakdown and decompose. This leads harm towards the environment as plastic takes up about 10% of our total waste stream, and it is composed mainly of the non-renewable resource petroleum.

However, there are ways where plastics can be broken down. One of the ways is to burn the plastic, this is not 100% guaranteed that the plastic will breakdown completely. In some cases, burning plastic can release toxic fumes. Burning the plastic polyvinyl chloride (PVC) may create dioxin. Not to mention, manufacturing of plastics often create large quantities of chemical pollutants. As the raw materials which plastic is created from consist of petroleum and natural gas, the more petroleum we burn to make new plastic products, the more greenhouse gases we release into the air.

3.2 Project Literature Review

3.2.1 Abstract

Our local East Riding of Yorkshire Council is trying to reduce the amount of waste by recycling different types of waste. However, not all plastics can be recycled by the council currently. The aim of this project is to develop a device that can distinguish between the different types of plastic which can be and cannot be recycled with the help of an infrared spectrometer. The system takes advantage of the different near infrared spectra from plastics of economic interest (eg. PVC, PET, HDPE). Materials can be identified by comparing their spectra to reference spectra. Spectra data are processed on line by means of an algorithm based on wavelengths to achieve a positive identification. This work describes the construction of a cheap and simple automatic classification system to do this at home. This could be in a form of a box containing an infrared source that will illuminate the plastic to be tested, perhaps through a set of filters of plastics that can be recycled. If the light passes through both filter and plastic under test onto a detector this will collect the radiation and pass a signal to an electronic circuit to indicate its suitability for recycling. This identification method is inexpensive to build and provides the necessary speed and performance required by the recycling industry.

3.2.2 Introduction

The UK produces 3 million tonnes of plastic waste each year, of which 85% is landfilled, 8% is incinerated and only 7% recycled. Natural resources are becoming scarce, landfills are growing and the green house effect is frequently on the agenda of world top conferences. Thus, recycling sector activity has grown more rapidly during the last decade. This has raised awareness amongst the public that there's a need to preserve the environment. To achieve that goal, several recycling plants have been built in many countries on the verge of recovering several kinds of materials.

There are different types of material that are recyclable, a few examples which are of successful reprocessing would be paper, glass or cans. Recycling plastics has become a big awareness to the public is because they are used extensively in almost all industrial activity. Due to the chemical stability in plastics, degradation of plastics takes a long time and produces a great environmental impact. (JM Barcala et al., 2003) However, plastics can be economically recycled. Due to the fact that not all plastics can yet to be recycled, the first step of the recycling process is to sort the different types of plastics which can and cannot be recycled. Automating the sorting process will improve profit margins for small-scale recycling operations and is essential for any large scale effort. (Pendleton et al., 1994)

In the basic recycling process, the plastics will be sorted out first and then the same types of plastics like PVC would be categorized independently and it would be recycled separated from the other plastics. Once the plastic has been identified, it is thrown onto a conveyor belt carrying of the same type to be recycled. The sorting plastics process is very crucial in a recycling process because in the case of polyethylene terephthalate (PET) and polyvinyl chloride (PVC) plastics, the two resins cannot be distinguished by sight alone. It is essential to distinguish accurately between these particular polymers because if there is a presence of PVC in the PET re-molding process, it would ruin the PET resin. (Edward J. Sommer, 2001) Therefore, this project aims to develop an inexpensive and simple device to help distinguish between the different types of plastics so it would be more efficient.

The main idea in developing a simple device that can be placed at home, university, public recycling areas so that the public can make use of the device to distinguish between the recyclable and the non-recyclable plastics. In that way, we actually help reduce the work of the recycling sectors because the plastics would be sorted out individually before it is sent to the recycling companies.

The project intend to build a near infrared spectrometer based on acoustic-optic filter and used wavelengths to analyze the obtained spectra. (JM Barcala et al., 2003) The near-infrared spectroscopy (NIRS) is a spectroscopic method which uses the near infrared region of the electromagnetic spectrum extends from about 750 to 2500 nm in wavelength. NIRS is based on molecular overtone and combination vibration, the electromagnetic energy in this case which is light is absorbed by polymers via the first overtones of the normal modes of vibration involving stretching of the C-H and O-H bonds. (YJ Pendleton et al., 1994) The analysis of NIR absorption can be used to obtain information about the chemical structure of a polymer sample. Hence, each type of plastic can be determined by their unique signature by measuring the absorption of light at a certain wavelength.

Absorbance at a particular wavelength λ is defined to be :

$$A_{\lambda} = -\log_{10}\frac{I(\lambda)}{I_0(\lambda)}$$

where $I_0(\lambda)$ is the intensity of light incident on the sample and $I(\lambda)$ is the intensity of light transmitted through it. (DM Scott, 1994)

The first step to the construction of the device is by determining each plastic's unique spectra, these data will be recorded. For example, after some experiments conducted by DM Scott, in the region between 1000 and 2000 nm, the dominant absorbance peak in PET is at 1660 nm and for PVC is at 1716 nm. (DM Scott, 1994) These data collected from these experiments will be used to compare with an unknown sample to determine the polymer type. The relative factors that would disrupt the process would be the contamination levels typically found in consumer plastic waste streams and also the sample thickness, as the absorbance of light is proportional to the thickness of the sample. Therefore the sample has to be cleaned and broken down to a specific thickness before it can be placed into the device.

The project could be in the form of a box with an insertion hole in the middle of the box. There should be a separation of space to provide room for passage of the crushed, small, or large sized bottles. Inside the box, there will be an infrared source (IR LED) that will illuminate the sample plastic. There will be a lens in between the source and the detector, the lens acts to collimate the infrared light towards the detector. An interference filter will be placed before the detector, which selects the wavelengths of interest, so the corresponding detector measures the light intensity at that wavelength only. If light passes through both filter and plastic under test onto a detector, the radiation received will be collected and pass the signal to an electronic circuit to indicate what type of plastic it is. The circuit is assumed to use the spectra obtained from the plastic sample and compare it with the other reference spectra data that is stored in the memory of the circuit. The results from the analysis of the plastic could be displayed through an LCD screen that could be placed in front of the device.

3.3.3 Conclusion

Plastics cannot be distinguished by sight alone, therefore a device to help distinguish the plastics for recycling purposes would be useful. The NIR spectroscopic method is currently being used in recycling companies to quickly sort bottles according to polymer type in plastics recycling operations. The proposed project is to develop a simpler device using similar method so that the public can help sort out between plastics. The method is based on the observation that a certain peak in the NIR absorption spectrum shifts according to each polymer's spectra. Once each different plastic has been sorted out individually, the recycling process would be more efficient. Another factor is with the presence at a very low level of a different polymer, it is able to destroy the uniformity and utility of the recycling materials. However, there might be a few factors that disrupt the NIR process, which is based on the color or thickness of the plastics. Dark colors may produce inaccurate wavelengths due to the inaccurate absorption of light. On the other hand, the thickness of the plastic material may also lead to more absorption of light. Hence, there might be certain specifications required before the plastic sample can be placed into the device.

The further research on this project can include automated image analysis to the identification and extraction of recyclable plastic bottles. The development of this automatic sorting system uses available image processing techniques where images of the bottles are digitized, pre-processed with standard filter algorithms, and then analyzed to extract meaningful features of the objects in the image. The classifying process also requires the comparison of the extracted features with those present in a database. (Edgar Scavino et al., 2009)

3.4 Public Awareness Around The University Of Hull

The amount of plastic waste generated annually in the UK is estimated to be nearly 3 million tones. An estimated 56% of all plastics waste is used packaging, three-quarters of which is from households. It is estimated that only 7% of total plastic waste arisings are currently being recycled.

In order for England to achieve its challenging recycling targets, the Government recognized that there's a need for a distinct style of campaign, one that creates compelling reasons for consumers to act. Awareness of recycling in consumers' mind is not enough, the awareness needs to be turned into action. Creating actions is the primary focus of the new campaign.

As playing a role in the recycling campaigns, The University Of Hull has recycling bins all around the university. Recycling bins of all kinds, including one for each and every material, there's a clear separation for every material.

Figure 11: Recycling bins found around the University

As it can be seen from the Figure*** above, these example bins can be found all around university, including every floor on the library, in all faculties, in walkways and corridors. The bins are also labeled with the materials which can be placed into the bins. Therefore, students can easily identify what litter to be placed into which bin.

This is a step forward towards encouraging the benefits of recycling and to reduce any source of waste.

3.5 Environmental Pollution: The Harmful Effect Of Plastic Materials

Plastics are durable and degrade very slowly, the molecular bonds that make plastic so durable make it equally resistant to natural processes of degradation. Ever since the 1950s', one billion tons of plastic have been discarded and may persist for hundreds or even thousands of years.

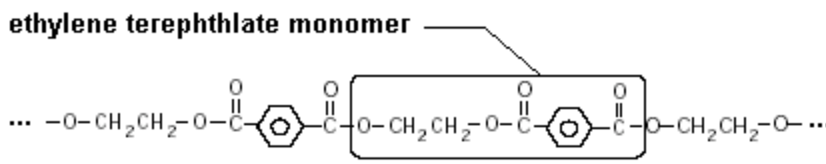
Here are a few examples of why plastics are a harmful effect to the environment:

- Polyvinyl chloride forms dioxins when burned and hydrochloric acid. It may contribute to dioxin formation from other wastes because it contains a big amount of chlorine. The more chlorine a dioxin, furan or PCB has, the toxic level will increase. Hydrochloric acid can irritate and burn lungs and cause fluid build up and there is a possibility of ulceration in human's respiratory tract. These effects will conclude to shorten one's life as dioxin can cause cancer, immune dysfunction, IQ deficit, reproductive effects etc.
- Polystyrene (Styrofoam) releases styrene and benzene, a carcinogen. When the material is burned, dioxins and chlorinated furans are formed, which are also carcinogenic. Styrene gas is very easily absorbed through the skin, respiratory system and gastrointestinal tract. High doses of these gases can cause deep unconsciousness and death. The vapour can damage the eyes and mucous membranes. These gases have the potential of accumulating in the human body for the entire life.
- Plastic bags kill animals. About 100,000 animals such as dolphins, turtles, whales, penguins are killed every year due to the littering of plastic bags. Many animals ingest plastic bags by taking them as food and therefore die. Even after the decomposition of the animal, the ingested plastic bag still remains intact.
- Plastic bags litter the landscape. Each year more and more plastic bags are ended up littering the environment. They do not decompose and will be found scattered around the environment. If these plastic bags are burned, they will infuse the air with toxic fumes, which leads to air pollution.
- Petroleum is required to produce plastic. As it is, petroleum products are diminishing and getting more expensive by the day. Petroleum is vital for our modern way of life, it is necessary for energy requirements. Therefore, this limited resource should be used wisely compared to having to use it to produce plastic.

3.6 Plastic Types and Symbols

Plastic bottles, containers and packaging typically have a symbol that indicates the type of plastic resin from which the item was made. The symbols imprinted on plastic bottles, containers and packaging are a variation of the original three wide mobius arrows. The symbol can usually be found on the bottom of a bottle, molded into the plastic itself as a raised impression and thus not always easily seen. The symbol includes a number within the mobius arrows, there will usually be a chemical resin below the mobius arrows in acronym form. Although presence of the symbol implies that the plastic item is recyclable, the symbol is only intended to identify the plastic resin from which the item was made.

3.6.1 Polyethylene Terephthalate (PETE or PET)



Molecular Formula: (−□□−□6□4−□□−□−□□2−□□2−□−)□

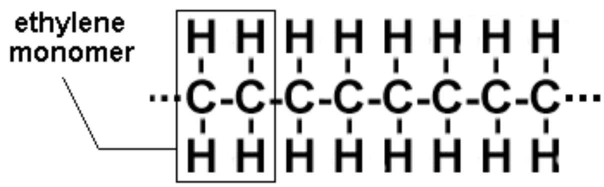
Properties: toughness, strength, heat resistance, barrier to moisture and gas.

Description: PET (polyester) is a popular packaging material for food and non-food products because it is inexpensive, lightweight, resealable, shatter-resistant and recyclable. PET is clear and has a good moisture and gas barrier properties. The flakes and pellets of cleaned postconsumer recycled PET are in heavy demand for use in spinning carpet yarns and producing fiberfill and geotextiles.

Packaging applications: Soft drink bottles, water bottles, beer bottles, mouthwash bottles, peanut butter containers, juice bottles, vegetable oil bottles.

Recycled products: Fiber, tote bags, new PET containers for both food and non-food products, fabric for clothing, athletic shoes, luggage, furniture, carpet, bumpers, film, automotive parts.

3.6.2 High Density Polyethylene (HDPE)



Molecular Formula: $(-CH_2-CH_2-)_n$

The $C=C$ double bond in an ethylene monomer is transformed into a $C-C$ single bond in the polymer.

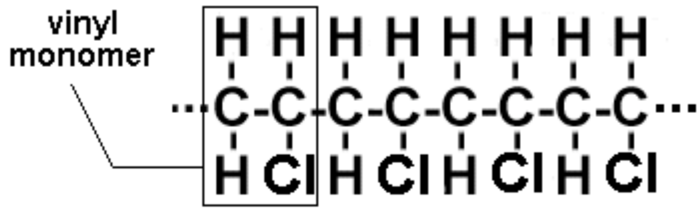
Properties: toughness, strength, stiffness, ease of forming, ease of processing, resistance to moisture and chemicals, permeability to gas.

Description: Bottles made from HDPE come in pigmented and unpigmented resins. The unpigmented resin is translucent. It also has good stiffness and barrier properties. Thus, it is ideal for packaging products having a short shelf-life such as milk. HDPE's good chemical resistance allows it to be used in containers holding household or industrial chemicals. The pigmented resin has even better crack resistance and chemical resistance than the unpigmented resin.

Packaging applications: Milk containers, juice bottles, watter bottles, bleach, detergent, and shampoo bottles, trash bags, grocery and retail carrying bags, motor oil bottles, butter and margarine tubs, household cleaner bottles, yogurt containers, and cereal box liners.

Recycled products: Drainage pipe, liquid laundry detergent bottles, oil bottles, pens, benches, recycling containers, floor tile, picnic tables, fencing, lumber, and mailbox posts.

3.6.3 Polyvinyl Chloride (PVC)



Molecular Formula: $(-CH_2-CHCl-)_n$

The $C=C$ double bond in each monomer is transformed into a $C-C$ single bond in the polymer.

Properties: toughness, strength, ease of blending, ease of processing, resistance to grease, oil, and chemicals, clarity.

Description: Polyvinylchloride has stable electrical and physical properties, It has excellent chemical resistance and good weatherability. Its flow characteristics make it well-suited for injection molding.

Packaging applications: Window cleaner bottles, cooking oil bottles, detergent bottles, shampoo bottles, clear food packaging, wire and cable jacketing, medical tubing, with additional significant usage in household products and building materials, particularly siding, piping and windows.

Recycled products: Binders, decking, paneling, mudflaps, roadway gutters, flooring, cables, speed bumps and mats.

The Cl (chlorine atom) in the molecular formula renders PVC a potentially toxic material when it is burned. Burning PVC can result in the creation of dioxins, a material that is considered highly carcinogenic.

3.6.4 Low Density Polyethylene (LDPE)

Molecular Formula: $(-CH_2-CH_2-)_n$

Properties: toughness, strength, flexibility, ease of sealing, ease of processing, barrier to moisture.

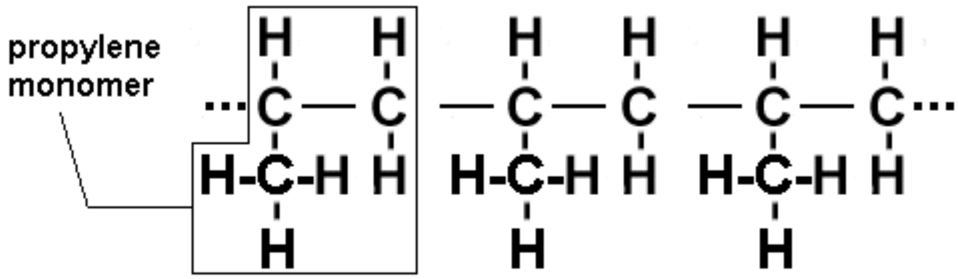
Description: LDPO is commonly used in applications where heat sealing is necessary because of its toughness, flexibility and transparency. It is also widely used in wire and cable insulation and jacketing.

Packaging applications: Squeezable bottles, breadbags, frozen food bags, tote bags, clothing, furniture, dry cleaning bags and carpet.

Recycled products: Film and sheet, loor tile, garbage can liners, shipping envelopes, furniture, compost bins, paneling, trash cans, lumber, landscaping ties.

The molecular formulas for LDPE and HDPE are the same. The difference in the plastics is the density of the molecular chains. The density varies in the manner in which the polymeric chains form. In HDPE the chain is essentially one long continuous chain, allowing the strands to fold back upon one another and densely occupy space. In LDPE the chains have multiple branches, which interfere with a neatly organized packing of chains. The packing is instead more disorganized, occupying more space and thus resulting in a lower density.

3.6.5 Polypropylene (PP)



Molecular Formula: $(-CH CH_3-CH_2-)_n$

The $C=C$ double bond in each monomer is transformed into a $C-C$ single bond in the polymer.

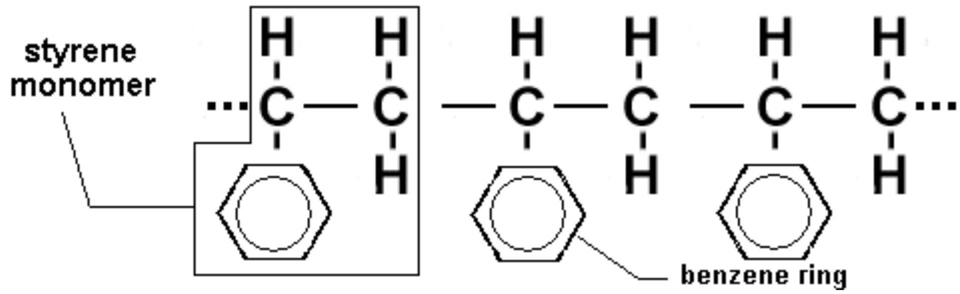
Properties: toughness, strength, resistance to heat, grease, oil and chemicals, barrier to moisture.

Description: Polypropylene has the lowest density of the resins used in packaging. It is strong and is resistant to chemicals. One of the features of polypropylene is that it has a high melting-point, therefore it can be utilized in applications which is used to handle and hot liquid.

Packaging applications: Yogurt containers, syrup bottles, ketchup bottles, caps, straws, medicine bottles.

Recycled Products: Signal lights, battery cables, brooms, brushes, auto battery cases, ice scrapers, landscape borders, bicycle racks, rakes, bins, pallets and trays.

3.6.6 Polystyrene (PS)



Molecular Formula: $(-CHC_6H_5-CH_2-)_n$

The $C=C$ double bond in each monomer is transformed into a $C-C$ single bond in the polymer.

Properties: ease of forming, clarity, low heat transfer, good thermal insulation.

Description: Polystyrene can be made into rigid or foamed products. It has a relatively low melting point.

Packaging applications: Plates, cups, cutlery, meat trays, egg cartons, carry-out containers, aspirin bottles, compact disc jackets.

Recycled products: Thermal insulation, light switch plates, egg cartons, vents, rulers, foam packing, carry-out containers.

C_6H_5 in the molecular formula comprises a benzene ring. Benzene is generally considered a carcinogenic substance.

3.6.7 Other

Properties: varies according to constituent resins

Description: The category of "Other" includes any resin not specifically numbered 1, 2, 3, 4, 5, or 6, or combinations of one or more of these resins.

Packaging applications: Three and five gallon water bottles, certain food product bottles.

Recycled products: Plastic lumber, custom-made products.

3.7 Why Recycle Plastics?

In 'western' countries, plastic consumption has grown at a tremendous rate over the past two or three decades. In the 'consumer' societies of Europe and America, scarce petroleum resources are used for producing an enormous variety of plastics for an even wider variety of products. Many of the applications are for products with a life-cycle of less than one year and then vast majority of these plastics are then discarded. In most instances reclamation of this plastic waste is simply not economically viable.

There is a growing move towards reuse and reprocessing of plastics for economics, as well as environmental reasons, with many examples of companies developing technologies and strategies for recycling of plastics. There is much awareness between the public as well when there were a lot more campaigns which was held to encourage the practice of recycling.

Plastic is not only made from a non-renewable resource, it is generally non-biodegradable. Even if it is, the biodegradation process is very slow. This means that plastic litter is often the most objectionable kind of litter and will be visible for weeks or months, and waste will sit in landfill sites for years without degrading.

Although there is also a rapid growth in plastics consumption in the developing world, plastics consumption per capita in developing countries is much lower than in the industrialized countries. There plastics are, however, often produced from expensive imported raw materials. There is a much wider scope for recycling in developing countries due to several factors:

- Labour costs are lower.
- In many countries, there is an existing culture of reuse and recycling, with the associated system of collection, sorting, cleaning and reuse of 'waste' or used materials.
- There is often an 'informal sector' which is ideally suited to taking on small-scale recycling activities. Such opportunities to earn a small income are rarely missed by members of the urban poor.
- There are fewer laws to control the standards of recycled materials.
- Transportation costs are often lower, with hand or ox carts often being used.
- Low cost raw materials give an edge in the competitive manufacturing world.
- Innovative use of scrap machinery often leads to low entry costs for processing or manufacture.

In developing countries the scope for recycling of plastics is growing as the amount of plastic being consumed increases.

3.8 Identification of different types of plastics

There are several simple tests that can be used to distinguish between the common types of polymers so that they may be separated for processing.

The few methods are as follows:

1. The water test – after adding a few drops of liquid detergent to some water, put in a small piece of plastic, see if it floats.
2. Burning test – hold a piece of plastic in a tweezer and apply a flame. Observe if the plastic burns, if so, observe the flame colour.
3. Fingernail test – test if a sample of the plastic can be scratched with a fingernail.

Test	PET	PP	PS	PVC
Water	Floats	Floats	Sinks	Sinks
Burning	Blue flame with yellow tip, melts and drips.	Yellow flame with blue base.	Yellow, sooty flame and drips.	Yellow, sooty smoke. Stops burning if flame is removed.
Smell after burning	Candle wax	Candle wax – less strong	Sweet	Hydrochloric acid
Scratch	Yes	No	No	No

Table 5: Simple test of identifying plastics

These are just simple tests to identify between the different types of plastics. They are not exactly accurate in every way. Plus, it's not encouraging to burn plastics indoors to identify what kind of plastic it is. Therefore, having a solution to identify plastics where no burning process is required would be better for indoor use, it also doesn't expose us to the chemical gas which is released from the plastic material.

4.0 Background Research

4.1 A two-colour near-infrared sensor for sorting recycled plastic waste (DM Scott)

Based on an article ‘A two-colour near-infrared sensor for sorting recycled plastic waste’ by D M Scott, the article describes a simple device for automated sorting of post-consumer plastic waste. The effectiveness of the proposed method is demonstrated in sorting of polyethylene terephthalate (PET) and polyvinyl chloride (PVC).

Most sources of recyclable material provide a random mixture of various plastic types, but recycling processes generally require a single polymer to be used. Therefore, the first step of the recycling process is to sort the input waste stream into its components.

In a typical recycling plant, bales of crushed, dirty bottles and containers are broken apart and spread onto conveyor belts for manual separation. Accurate separation depends on the ability of unskilled workers to recognize particular types of bottle or container against a background of other types. Once a bottle has been identified, it is thrown onto another conveyor belt carrying bottles of the same type.

In the case of polyethylene terephthalate (PET) and polyvinyl chloride (PVC) plastics, the two resins are difficult to distinguish by sight alone. The difficulty is compounded by some manufacturers that indiscriminately use either PET or PVC to make identical bottles for identical products. It is essential to distinguish correctly between these particular polymers because the presence of PVC in the PET re-molding process, even at the level of a few parts per million, will ruin the PET resin.

4.1.1 Near-infrared absorbance spectra

According to D M Scott, PVC and PET resins can be distinguished by measuring the absorption of light at a few well-chosen wavelengths, therefore, it is possible to obtain a unique signature for each type of plastic. The near-infrared (NIR) region of the electromagnetic spectrum extends from about 750 to 2500 nm in wavelength. In this region, electromagnetic energy (light) is absorbed by polymers via the first overtones of the normal modes of vibration involving stretching of the □−□ and □−□ bonds. Consequently, it is well known that analysis of NIR absorption can be used to obtain information about the chemical structure of a polymer sample. Therefore, this method is used to measure the absorption of light at certain wavelengths by each type of plastic. The spectra obtained from each type of plastic can be distinguished to the specific type of plastic. When there's an unknown sample amongst all the other plastics, the spectra of this unknown sample could be used to compare with the other known plastics to determine the polymer type.

The NIR absorbance spectra of the plastic samples collected were in the range of 1100-2500 nm. Samples of different types of plastics were collected and measured using a commercial spectrometer. The samples collected consist of clear PET, green PET and PVC, and they were not cleaned or rinsed, just left as they were initially. This is to compare the effect of the contamination of the bottle against the measuring spectra process.

The samples were then tested using the spectrometer to obtain the spectra required.

According to the experiments conducted, the absorbance spectrum of a polyethylene terephthalate (PET) and polyvinyl chloride (PVC) are as follows:

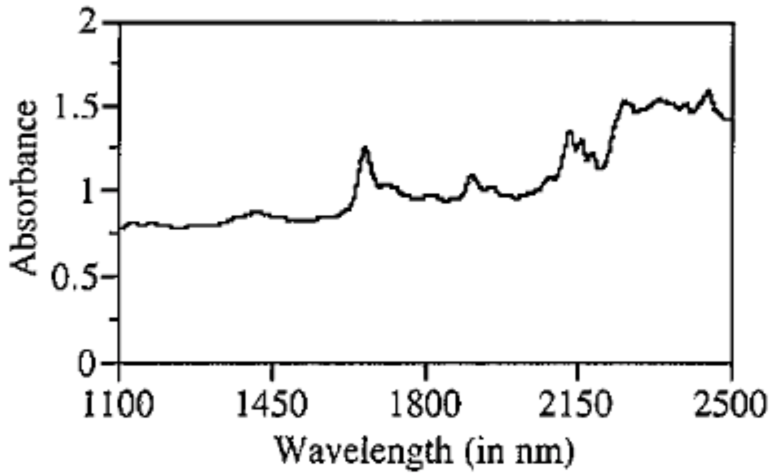


Figure 12: Absorbance spectrum of PET

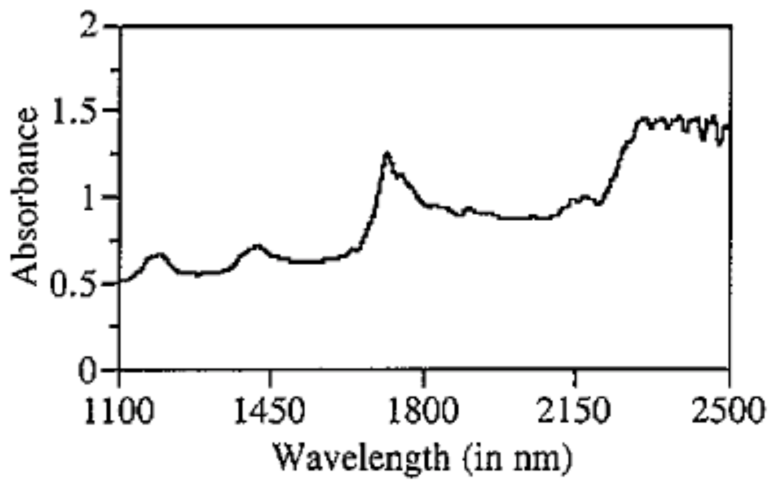


Figure 13: Absorbance spectrum of PVC

According to the experiments, the spectra proved to be consistent in spite of dirt and labels. Thus, contamination levels typically found in consumer plastic waste streams apparently do not obscure the characteristic spectral features.

Referring to the absorbance spectrum of both materials as seen from Figure 12 and Figure 13, there is a single prominent spectral peak for both polymer types. As for PET, the dominant absorbance peak is at 1660 nm. Instead, the dominant absorbance peak is shifted to 1716 nm. This feature has been observed in a number of polymers and is attributed to the first overtone of ⍰−⍰ stretching. From Figure 13 above, the PVC exhibits two small, broad peaks at 1196 nm and 1422 nm.

From these observations, it was decided to focus on the absorbance at 1660 and 1716 nm. From the spectra, it would seem that PET may be distinguished from PVC by locating the wavelength of the first overtone of ⍰−⍰ stretching. The position of this spectral feature may be determined by measuring the ratio of the absorbance at 1716 nm to that at 1660 nm. If the polymer is PVC, then this ratio will clearly be greater than unity, whereas it will be less than unity in the case of PET. From this ratio, a simple threshold discriminator can separate the two polymers.

The variation noted between spectra of the polymers is in the total absorbance values and is attributable to variations in sample thickness. Absolute absorbance is directly proportional to the thickness of the sample, whereas relative absorbance is independent of sample thickness.

4.1.2 Simulation of a two-colour spectrometer

In order to emulate the device, the NIR spectra of plastic samples collected from the plant were convoluted with Gaussian functions representing the spectral transmission of both interference filters. These functions were centered on 1660 nm and 1716 nm, both having a full width of 15 nm and a peak transmission efficiency of 65%. Each convolution produced a single value to represent the output of each filer-detector combination.

According to D M Scott, taking the ratio of 1716 nm signal to the 1660 nm signal for the PET samples gave a mean value of 0.839, with a standard deviation of 0.019 and a range of 0.798-0.867. In contrast, the samples of PVC gave a mean ratio of 1.98, with a standard deviation of 0.623 and a range of 1.35-3.42. According to the data collected, it is clear that all PET ratio values fall unambiguously below unity, and all PVC ratio values fall unambiguously above unity. Setting a threshold near unity could easily discriminate between the two polymer types. This simulation suggests that a two-colour NIR spectrometer can distinguish PVC from PET in post-consumer recycling operations.

4.1.3 Hardware Implementation

Absorbance at a particular wavelength λ is defined to be:

$$A_\lambda = -\log_{10} \frac{I(\lambda)}{I_0(\lambda)}$$

Where $I_0(\lambda)$ is the intensity of light incident on the sample and $I(\lambda)$ is the intensity of light transmitted through it. The ratio $I(\lambda)/I_0(\lambda)$ is simply the transmission of the sample, so the absorbance is the magnitude of the common logarithm of the transmission. The wavelength can be selected by an appropriate interference filter that has a narrow pass-band centered on the wavelength of interest. Two filters are used in the present application to provide separate wavelength channels.

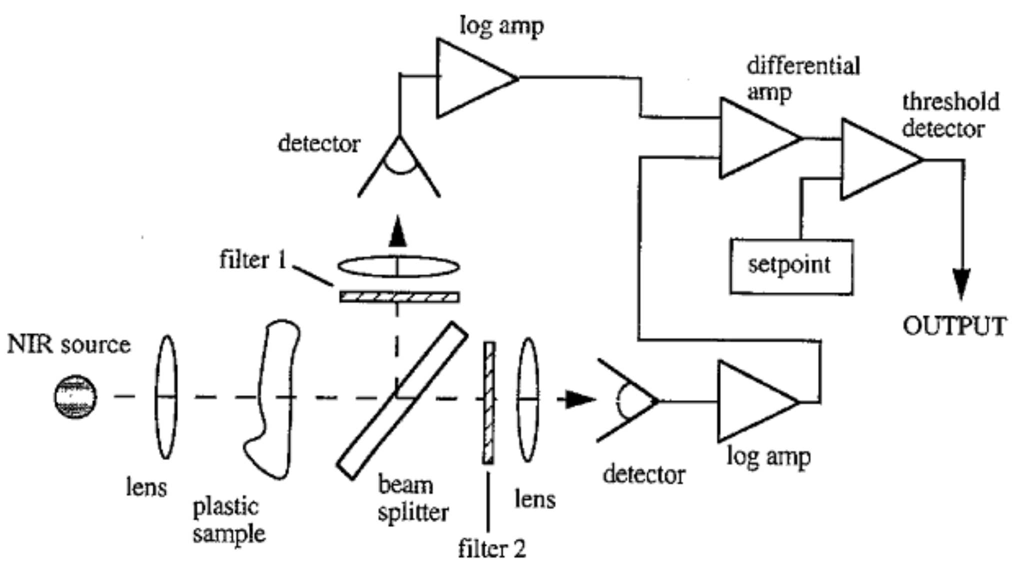


Figure 14:

Figure 14: The hardware implementation (D M Scott)

Figure 14 above shows a simple two-filter spectrometer suitable used by D M Scott for distinguishing PVC bottles and containers from PET bottle and containers n a post-consumer recycling operation. A broadband source of near-infrared light illuminates the plastic sample via a collimating lens. The source used for this hardware implementation is a 15W tungsten bulb which generates sufficient broad-band NIR illumination purposes, other NIR sources can be used for this application as well.

In any case, the colour temperature of the source should be stabilized so that the spectral output remains constant near the wavelength of interest. The lens used in the hardware is to collimate the light allows a separation of several inches between the source and detector. The separation is necessary when sorting applications to provide room for passage of the crushed bottles. Some of the transmitted light will be scattered out of the receiving aperture by the bottles, but it has been determined that a sufficient amount of the transmitted light can be collected.

As seen from the Figure 14, the light transmitted by the plastic bottle impinges on a beam splitter and is split into two beams of collimated light. There was no suitable splitter that was available, so one had to be devised. In order to guarantee the efficiency of the splitter in the NIR region, it was fabricated from copper shim stock, electroplated with gold and polished. Small holes covering 50% of its surface were punched in the shim, which was mounted at a 45° angle with respect to the light beam to create a 50/50 beam splitter. After the splitter, each collimated beam passes through an interference filter and a lens that focuses the light onto a detector, so that the corresponding detector measures the light intensity at that wavelength only.

The outputs from the detector pre-amplifies are conditioned by logarithmic amplifiers in order to make the signal linear with respect to absorbance. Absorbance measurements require the intensity ▯▯(▯) of incident light to be recorded for both wavelengths. If the NIR source is sufficiently stable the incident intensity amounts to a constant offset, and the amplifier gains can be adjusted to give a zero output from the logarithmic amplifier in the absence of samples. By definition, the measured intensity is equal the incident intensity under these conditions, and the negative logarithm of the transmission signal is an adequate measure of absorbance. Otherwise, reference channels consisting of filter-detector pairs to monitor the NIR source output can provide the necessary ▯▯(▯) signal. Normalization is effected by subtracting the logarithm of the transmission signal from the logarithm of the reference signal, thus yielding the absorbance. Subtracting the signal of the 1660 nm filter-detector from the absorbance signal of the 1716 nm filter-detector yields the logarithm of the ratio above or below unity. A threshold discriminator detects whether the ratio is greater or less than unity by checking the polarity of the logarithmic output, and a set-point control provides a means of balancing DC offsets in the system.

When a PVC bottle enters the light beam, the ratio exceeds the threshold, and the output signal becomes high. This signal may be used to activate an air blast to remove the PVC bottle from the PET line. The sensor thus provides an automatic means of detecting and removing PVC.

The device shown in Figure 14 was built and demonstrated in the laboratory. The two-colour sensor was consistently able to distinguish between PVC and PET samples. The problem noted with this device was with the signal drift. The detectors used for this hardware was the InAs detectors operating in DC mode at ambient temperature were used in conjuction with 15 nm, 65% transmissive band-pass filters. In general, the signal strength is adequate, but there is also a significant dependence of the dark current on temperature variations. The resulting shifts in DC signal level preclude reliable measurements in an industrial setting. For this reason, the detectors should be cooled.

4.2 Automated sorting of plastics for recycling (Edward A Bruno)

This paper presents a synthesis of available information on automated sorting of plastics. The information is broken into two categories: macrosorting and microsorting. The macrosorting section deals with the sorting of whole bottles or containers. The macrosorting section covers the following technologies: infrared spectroscopy, x-ray, laser-aided identification, and marker systems. The microsorting section follows the sorting of plastics after it has been chopped into pieces. The section covers the following areas: sink float systems, froth-floatation, and selective dissolution.

4.2.1 Macrosorting

4.2.1.1 Spectroscopy

As reviewed by D M Scott's article, near-infrared spectroscopy is one of the most promising prospects for automated sorting of post-consumer plastics. When infrared light reflects off the surface of the plastic, each resin's characteristic infrared absorption band can be measured.

This separation method has many advantages. For one, the advantage of using spectroscopy is the speed of identification. The scanning speed of the spectroscopic instrument allows many readings of one sample to be taken in short periods of time. The speed also provides for increased volume of plastics sorted in smaller amounts of time. The second advantage of spectroscopy is the lack of specimen preparation needed, the labels or other contamination on the samples do not interfere with any measurements taken. Another advantage of this system is that colour does not interfere with proper resin identification, this system does not work with black because black is a strong absorber in the near-infrared region, and scanning of black plastics result in a featureless spectrum.

4.2.1.2 X-RAYS

Another sorting option lies in the field of x-ray transmission and reflection. This method is similar to the infrared spectroscopic method discussed previously, this separation method exposes the unknown plastic to waves and studies the object's response. In this case, the transmission and reflection from waves in the x-ray region of the spectrum are studied. Most of this technology is being applied to the sorting of PVC. The chlorine atoms in PVC give a unique peak in the x-ray spectrum that is readily detectable.

4.2.1.3 Laser-aided identification

Another possibility for the automatic identification of plastics for sorting is laser-aided identification. This system identifies plastics by shining a laser beam onto the surface to be identified and then analyzing the material's response. At the Laser Zentrurn Hannover, a sorting method was developed which sorts out different plastics using a heat impulse response to identify different materials. The process uses a □□*2* laser to project a small beam spot onto the material to be identified. The system also works by using infrared thermographic system, various material properties including absorption coefficient, thermal conductivity, thermal capacity, and surface temperature distribution which are all recorded. These properties can then be analyzed to identify plastic type. The resulting system is suitable for quick analysis and identification of various plastics.

4.2.2 Microsorting

4.2.2.1 Sink Float Systems

Sink float separation systems are very common and simple methods of separating materials of different densities. The method simply involves depositing the materials in a tank filled with water or other liquid. The lighter materials float and the heavier ones sink. For a sink float system to work efficiently the materials' densities must differ greatly from one another. Some plastics, like PVC and PET, have very similar densities and cannot be separated by normal sink float system.

Materials		Density range $(g/cm3)$
Polyolefins	Polypropylene	0.916-0.925
	Low-density polyethylene	0.936-0.955
	High-density polyethylene	0.956-0.980
Non-olefins	Bulk polystyrene	1.050-1.220
	Polyvinyl chloride	1.304-1.336
	Polyethylene terephthalate	1.330-1.400

Table 6: Polymer density ranges (Atland et al. 1995)

The system being developed uses high-pressure, near-critical liquids as the separation media. At a critical point, the fluid's density is changed by altering the pressure. Therefore, by decreasing the pressure in small increments, the liquid density is also decreased in small increments. According to the study, the fluid density is then adjusted to an intermediate level between two types of plastics to be separated, causing one type to float and the other to sink. The low viscosity of the fluid causes the materials to rise or fall rapidly, even with small differences in densities between the particles and the liquid.

A gameplan was developed for separating the most common post-consumer plastics including PP, HDPE, LDPE, PS, PET, and PVC.

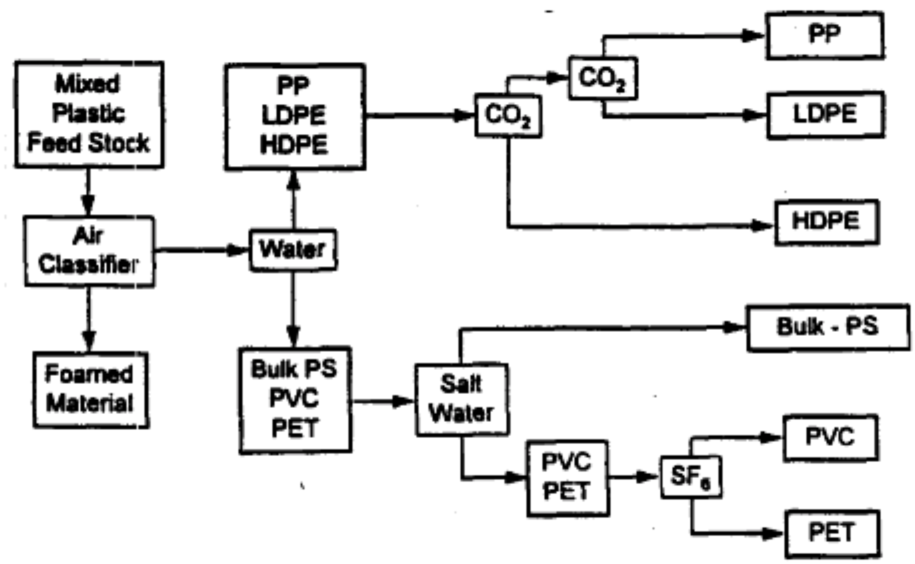


Figure 15: Proposed plastic recycling schematic with high-pressure separations (Atland et al. 1995)

The first step is to separate the lighter polyolefins (HDPE, LDPE, PP) from the heavier non-olefins (PS, PET, PVC). This is achieved using water as the sink-float medium. Next, HDPE is separated from LDPE and PP using a sink-float medium composed of near-critical carbon dioxide (CO_2). Also using CO_2, LDPE is then separated from PP. On the non-olefin side of the separation scheme, PS is removed in a saltwater solution. The remaining plastics (PVC and PET) are separated with near-critical sulfur hexafluoride (□□4). This technique is demonstrated to have the ability to separate differing colors of HDPE from their slightly different densities.

The results from the study shows that there was no overlap between the polyolefins, and they were cleanly separated in float-sink experiments with liquid CO_2 used as the separation medium. There was a single PVC packaging material that had a density in the range associated with the PET samples, however, that resulted in 95% recovery of the PET in a stream of 99% PET purity.

An economic study on the effectiveness of this separation method was also conducted with promising results.

5.0 Progress Work

5.1 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) is a technique which is used to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid, liquid or gas. An FTIR spectrometer simultaneously collects spectral data in a wide spectral range. This confers a significant advantage over a dispersive spectrometer which measure intensity over a narrow range of wavelengths at a time.

In infrared spectroscopy, infrared (IR) radiation is passed through a sample. Some of the infrared radiation is absorbed by the sample and some of it is passed through (transmitted). The resulting spectrum represents the molecular absorption and transmission, creating a molecular fingerprint of the sample. Like a fingerprint no two unique molecular structures produce the same infrared spectrum. This makes infrared spectroscopy useful for several types of analysis.

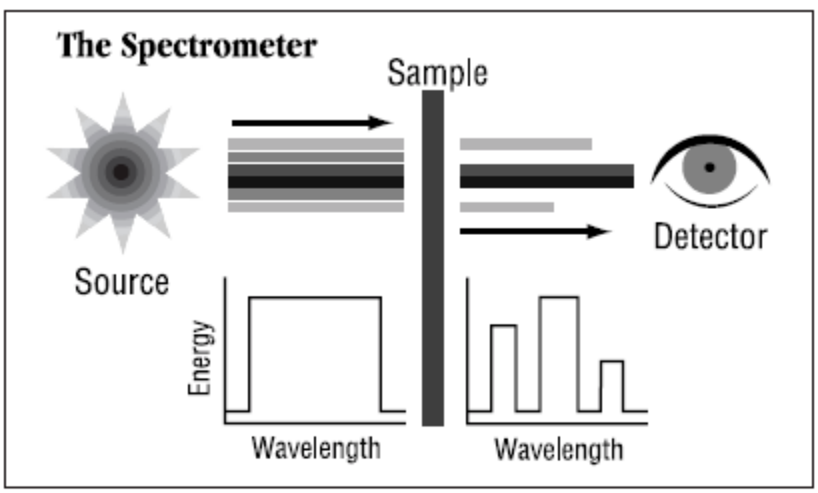


Figure 16: Example of how to obtain sample spectra using FTIR

The FTIR can provide information by identifying unknown materials, determining the quality or consistency of a sample and also determining the amount of components in a mixture.

5.2 The Sample Analysis Process

The normal instrumental process is as follows:

1. The Source: Infrared energy is emitted from a glowing black-body source. This beam passes through an aperture which controls the amount of energy presented to the sample or to the detector.
2. The Interferometer: The beam enters the interferometer where the "spectral encoding" takes place. The resulting interferogram signal then exits the interferometer.
3. The Sample: The beam enters the sample compartment where it is transmitted through or reflected off of the surface of the sample, depending on the type of analysis being accomplished. This is where specific frequencies of energy, which are uniquely characteristic of the sample, are absorbed.
4. The Detector: The beam finally passes to the detector for final measurement. The detectors used are specially designed to measure the special interferogram signal.
5. The computer: The measured signal is digitized and sent to the computer where the Fourier transformation takes place. The final infrared spectrum is then presented to the user for interpretation and any further manipulation.

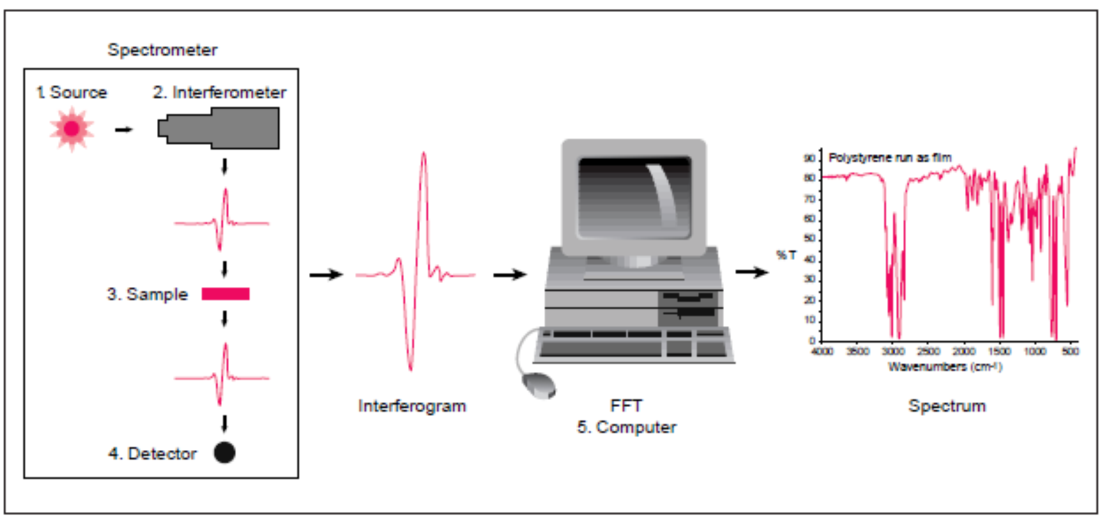


Figure 17: How an FTIR works

There is a need for a relative scale for the absorption intensity, a background spectrum must also be measured. This is normally a measurement with no sample in the beam. This can be compared to the measurement with the sample in the beam to determine the “percent transmittance”. This technique results in a spectrum which has all of the instrumental characteristics removed. Thus, all spectral features which are present are strictly due to the sample. A single background measurement can be used for many sample measurements because this spectrum is characteristic of the instrument itself.

5.3 Why Infrared Spectroscopy?

An infrared spectrum represents a fingerprint of a sample with absorption peaks which correspond to the frequencies of vibrations between the bonds of the atoms making up the material. Each different material is a unique combination of atoms, no two compounds produce the exact same infrared spectrum. Therefore, infrared spectroscopy can result in a positive identification of every different kind of material. In addition, the size of the peaks in the spectrum is a direct indication of the amount of material present. Due to all the benefits of infrared spectroscopy, the method used to determine what kind of material an unknown item is would be suitable with the concept of identifying plastics as well. Therefore, using infrared as a source to determine the how much transmittance it has against each plastic would be useful in the process of this project.

5.4 Obtaining spectra for plastic samples using the FTIR

Spectra were obtained using the FTIR spectrometer for 1, 2 and 3 layers of each type of plastic. A background scan was also obtained each time the spectrometer was used. As mentioned above, a background spectrum must always be measured when there's no sample in the beam so that it can be compared to the measurement with the sample in the beam to determine the transmittance of the spectra.

Each plastic sample was cleaned to remove any grease or contamination on the sample which might affect the spectrum obtained. After all clean samples have been tested to obtain the spectrum required, one of the plastic sample was left contaminated with a small amount of grease from the fingers. The spectra of the contaminated plastic sample was measured so that we could see the effect of grease which could change the spectra measured. This is required as the device for the project needed to tolerate plastics which are contaminated with water, dirt and others.

The data obtained from the experiments were transferred to Excel.

The transmittance of each plastic at a given wavenumber was calculated by using:

[illegible] = [illegible] ----- [illegible] (1)

[illegible] = [illegible] − [illegible] ----- [illegible] (2)

Where [illegible] = [illegible], [illegible] = [illegible], [illegible] = [illegible]ℎ[illegible] [illegible]ℎ[illegible] [illegible]

Rearranging the equation above gives

[illegible] = −ln[illegible] ----- [illegible] (3)

Using the Equation (3) as above,

The transmittance of 2 layers and 3 layers of plastic should be as:

$$\frac{\ln(Transmittance\ of\ 3\ layers)}{\ln(Transmittance\ of\ 2\ layers)} = \frac{3}{2} \text{-----} Equation\ (4)$$

The Equation (3) as calculated above is just an assumption of how the transmittance of a material could be identified. To prove if the equation is true, the resulting graph from Equation (4) should be a straight line of $y=1.5$.

The plastic layers must be of equal thickness.

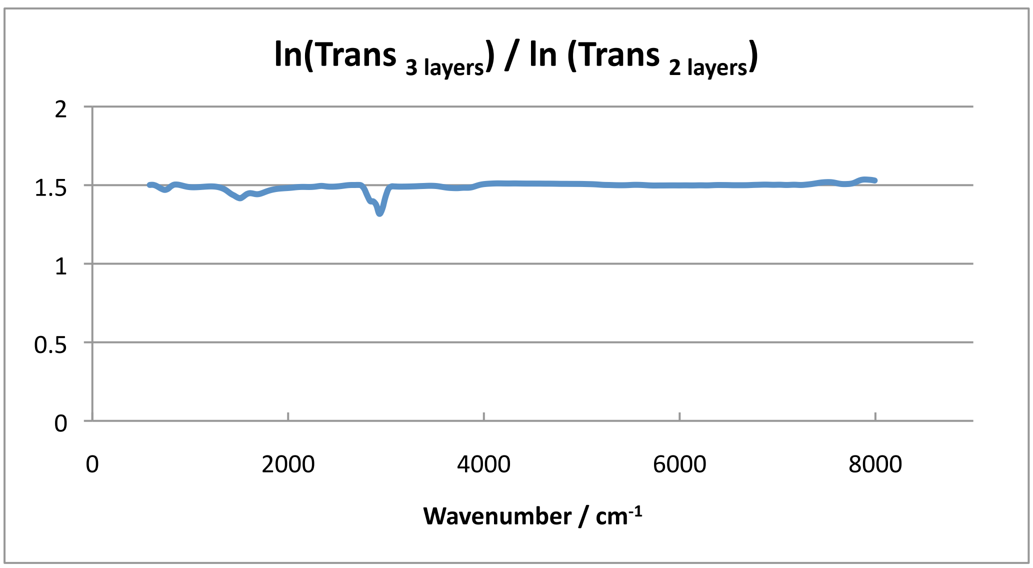


Figure 18: Resulting graph from Equation (4)

The graph shows a straight line at $y=1.5$. As it can be seen from Figure 18, the slight deviations are most likely caused by the fluctuations in material width, a saturated or non-linear detector or it could even be affected by the absorbance by air molecules.

The next step taken was to find the best possible means of distinguishing between the different types of plastics. Based on the background research, the best way would be to observe the absorbance peaks of the plastic spectrum at certain wavelength of interest and therefore distinguish the differences between each type of plastic.

There are 3 ways to look at a narrow region of the spectrum:

- Use a narrowband emitter and a wideband detector.
- Use a wideband emitter and a narrowband detector
- Use a wideband emitter, narrow band-pass filter and wideband detector

Due to the fact that narrowband emitters and detectors are expensive in the region of wavelength of interest, it was best to use a wideband emitter and narrow band-pass filter and wideband detector option to reduce costs so that the product would be more commercially viable.

There were 5 IR filters provided which was used to in the process of obtaining the spectra of each plastic. There were no given data or characteristics based on the 5 filters provided, the spectrum of all 5 filters were then measured with the FTIR spectrometer.

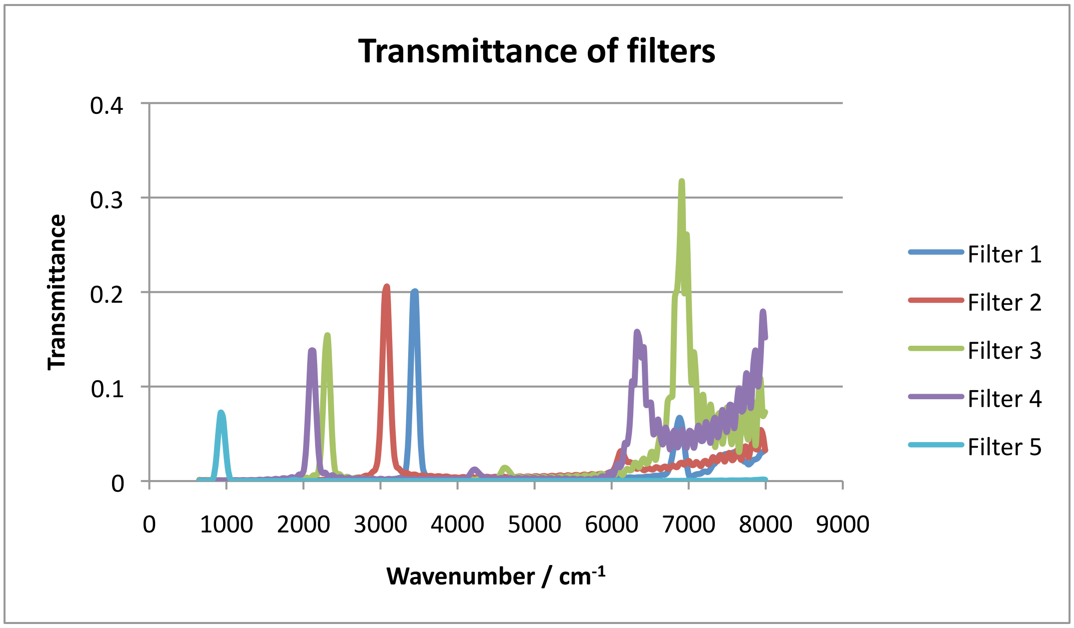


Figure 19: Spectra of all 5 different filters

The spectra obtained showed that 5 narrow band-pass filters with peaks at 3456, 3085, 2314, 2129, 956 cm^{-1} respectively. The spectra also shows peaks between 6000 and 8000 cm^{-1}, which is probably caused by the FTIR spectrometer having low sensitivity at these levels. These frequencies have wavelengths shorter than 1.7 microns, therefore the detector or source should detect or emit only wavelengths greater than 1.7 microns. The spectra also showed that filter 3 and filter 4 have small peaks at double their intended frequency of use, however, they may be not big enough affect the wanted results significantly.

The next step taken was to find a region of the spectra at which we could differentiate between recyclable and non-recyclable plastics.

After gathering spectra for 1, 2 and 3 layers of each plastic, the spectra of 1 layer of each type of plastic is plotted as follows.

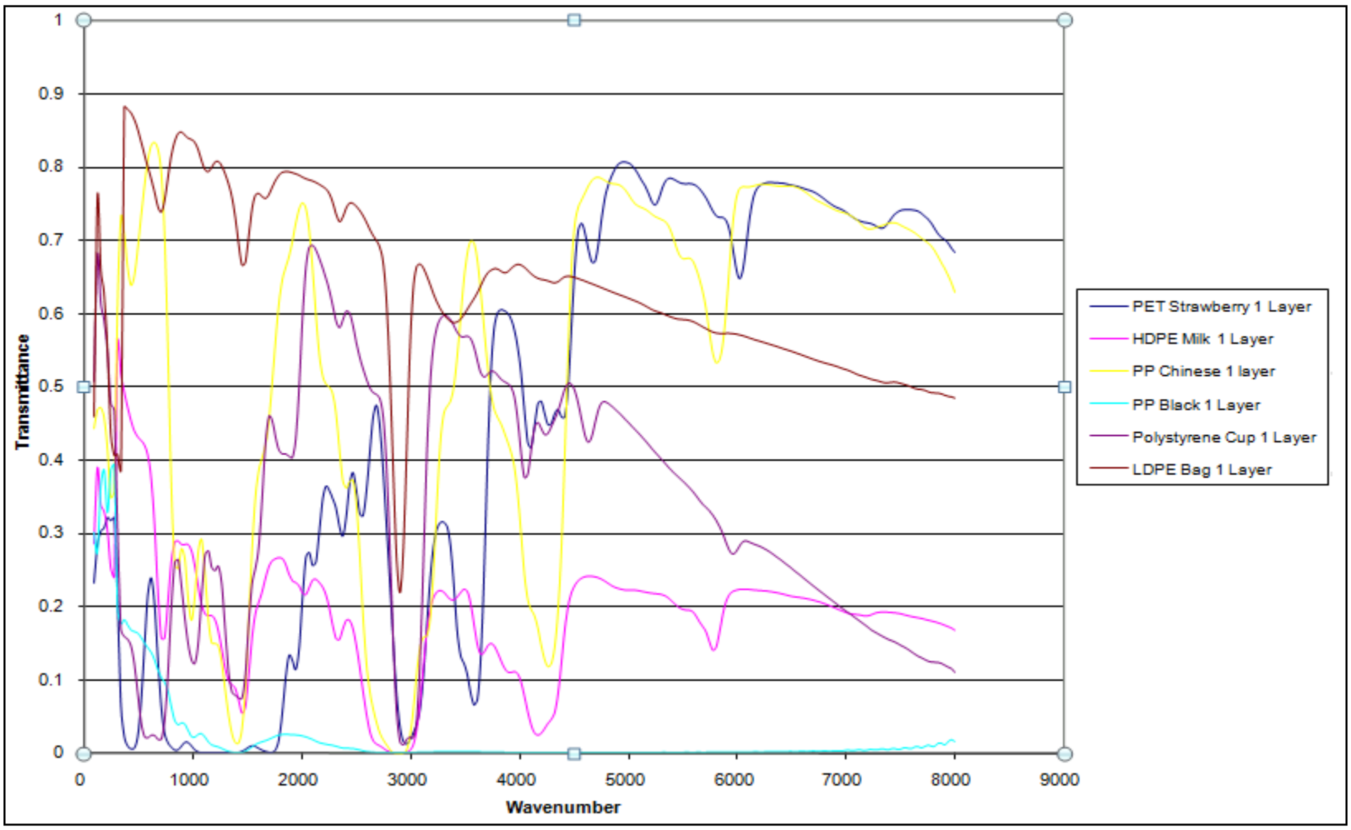


Figure 20: Spectra for 1 layer of different types of plastic

The Figure 20 above shows the spectra obtained from each and every different plastic samples collected which consisted of PET, HDPE, PP, PS and LDPE.

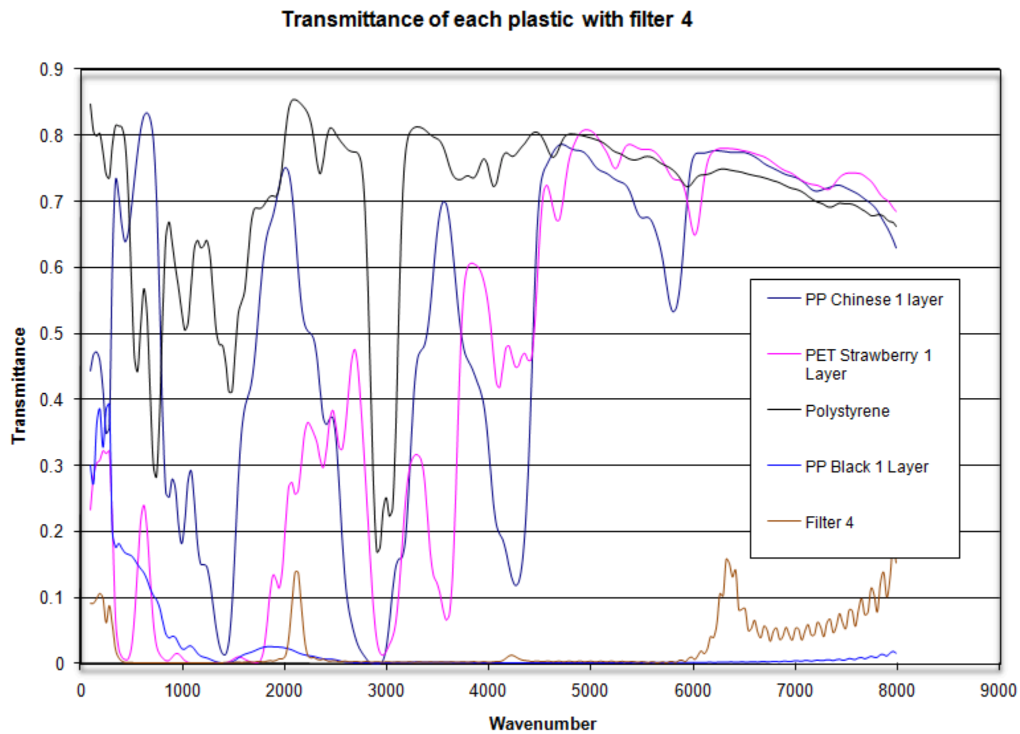


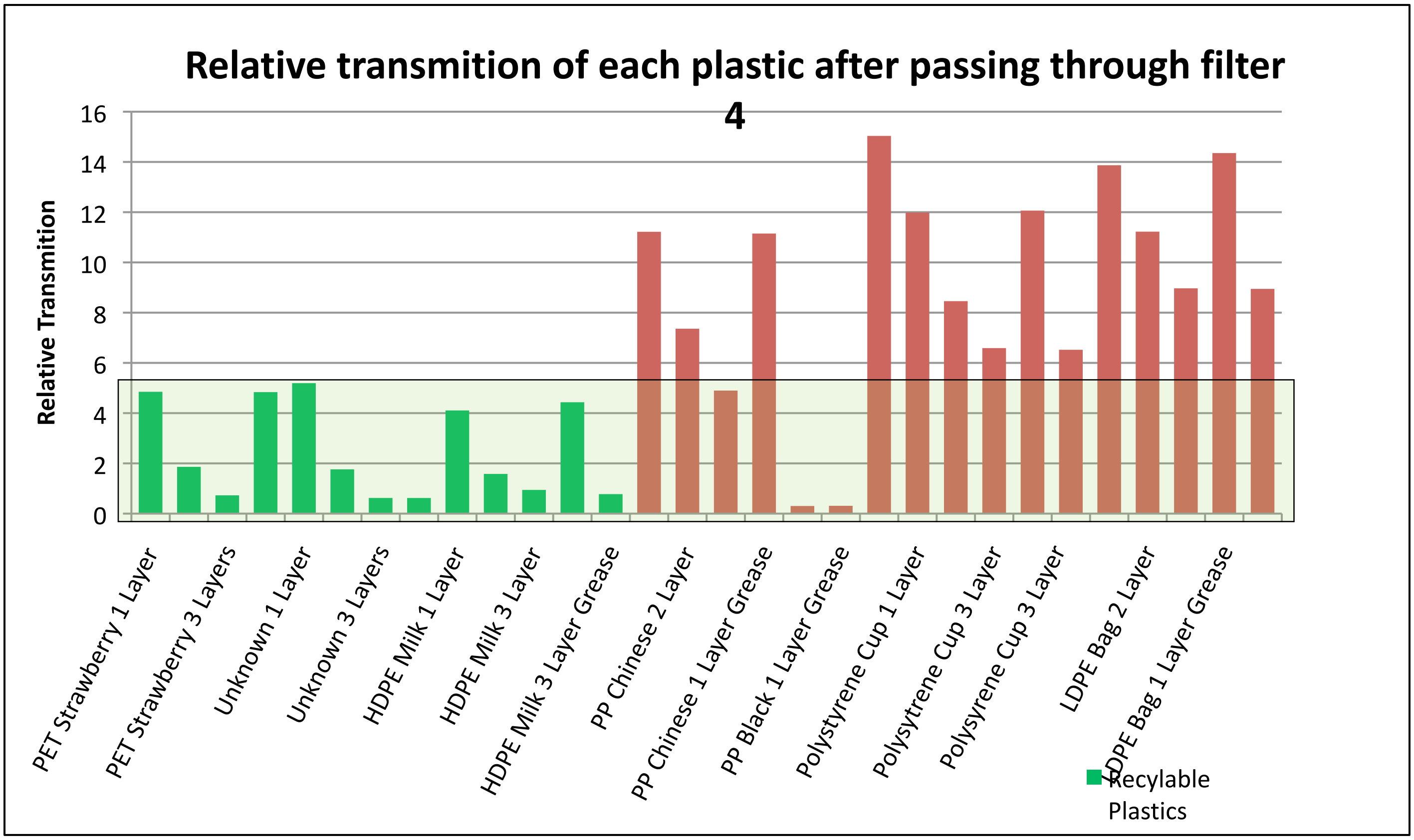
Figure 21: Transmittance of each plastic and filter 4

As can be seen from Figure 21, at 2129 cm^{-1} wavenumber, the Filter 4 transmission peak lies at that point. This means that at this wavenumber, the filter allows infrared signals to be transmitted through it, the other wavelength are all eliminated.

At this point, there is a clear separation between the different types of plastics because the transmittance of infrared light of each plastic is different, therefore it could be distinguished easily according to the transmittance value.

From Figure 21 above, Polystyrene has the highest transmittance of infrared light, it means that Polystyrene allows the most infrared light pass through it to be detected. The second highest transmittance is transparent Polypropylene, which is also a non-recyclable plastic, followed by PET and lastly the black Polypropylene, the black PP absorbed most of the infrared light leaving very little transmittance of infrared light through it.

It was then found that Filter 4, a band in the middle of the spectrum appeared where all the recyclable plastics lay, and all the other plastics were outside the region, with the exception of 3 layers of the Chinese box made from PP. However, it was considered that 3 layers of PP would be common among all



plastics. Therefore, the Chinese box made from PP was considered ignored in the process.

Figure 22: Relative transmittance of each plastic using Filter 4

As seen from Figure 22 above, this way the recyclable and non-recyclable plastics could be distinguished by referring to their relative transmittance of infrared. The red coloured blocks in Figure 22 represents the non-recyclable plastics which shows that these plastics have higher transmission of infrared light compared to the recyclable ones. The PP black plastic would absorb all the infrared light passing through and therefore there would be no transmission of light received from the detector.

5.5 Effect of plastic thickness

There were a few experiments carried out regarding the factor of thickness might affect the spectra obtained. Therefore, experiments were carried out using a few layers of plastic, and the differences between one layer or more could be observed.

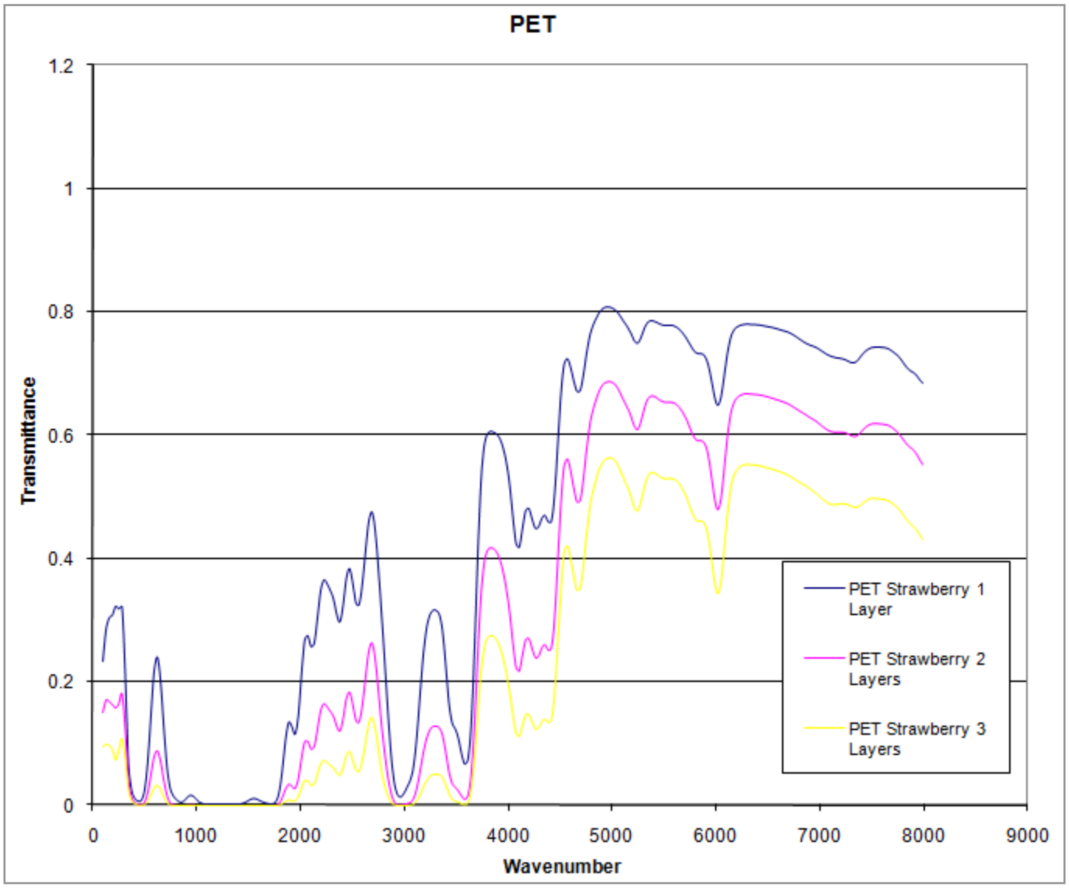


Figure 23: Transmittance of 1, 2 and 3 layers of PET

As it can be seen from Figure 23, the form of the spectra between 1, 2 and 3 layers of plastic is still the same. Even though the transmittance values are slightly different, the spectra still remains the same. The transmittance values of infrared signal reduces as the layers of plastic increases. This might be because the more the layers, the infrared signal could not transmit as much, there will be more absorption of infrared signal by the plastic. However, it does not really matter because the form of the spectra is still the same. This means that the transmission peaks of the spectra of the wavelength of interest are still the same, the different type of plastics will still be able to be distinguished regardless of the number of layers concerned. However, it is still one of the factors that may interrupt the process of sorting out different plastics.

5.6 Effect of contamination on the plastic

As mentioned earlier, there was a plastic sample that was left in its initial condition with grease on to test if contamination would affect the spectrum of a particular plastic.

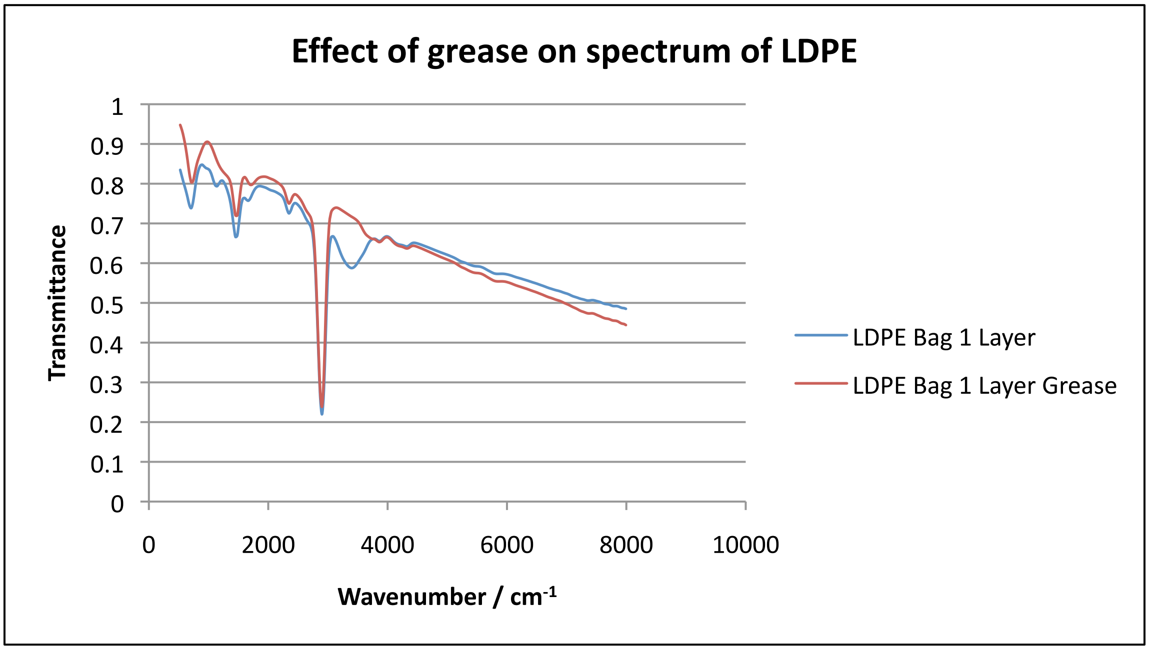


Figure 24: Effect of grease on plastic spectrum

Referring to Figure 24 above, the two spectra consists of one which is clean and free from grease and the other is contaminated with grease. There is not much difference between the two spectras obtained. Therefore, it could be concluded that contamination on the plastics will not affect the spectra of the particular plastic and it should be able to distinguish accurately. The contamination factor from plastic bottles will then be ignored.

5.7 Transmitters

As from experiments conducted, it was concluded that Filter 4 was the most suitable to help distinguish between recyclable and non-recyclable plastics. The emitter and detector needs to work at 2129□□−1 as that's where the peak of Filter 4 lies.

Most datasheets for components express the type of IR used as a wavelength (μ□) while the spectra obtained were all measured in wavenumbers.

To convert wavenumber to wavelength:

□□□□□□□□□ℎ□□= 10000□□□□□□□□□□□□□−1

=100002129

≈4.7□□

According to Wein's Law, there is a peak wavelength emitted by a black body:

□□□□= □□ , □/ℎ□□□ □=2.9 □ 10−3 □□□□ □□□□□□□□□

The wavelength required to be compatible is 4.7□□, therefore □□□□=4.7□□.

4.7 □ 10−6=2.9 □ 10−3□

□=617□=345°□

Therefore, a small electric heater operating at a temperature above 340°□ would be able to provide enough of power in the right region for the device.

A ceramic heater, which can be easily plugged into a light bulb socket has been chosen as the emitter for the device. The emitter is a V8 60W light bulb infrared source, the power output might be greater than what is required, however, it is cheap and readily available. They are also easier to install as there is no circuit required to make it work. It just needed a bulb holder and power supply.

5.8 Detectors

The wavelength of interest that would be suitable for this application was decided to be around $4.7\mu m$. a detector with a high detectivity has a high signal to noise ratio, therefore making it a better detector. The detector needed to have a high sensitivity around $4.7\mu m$.

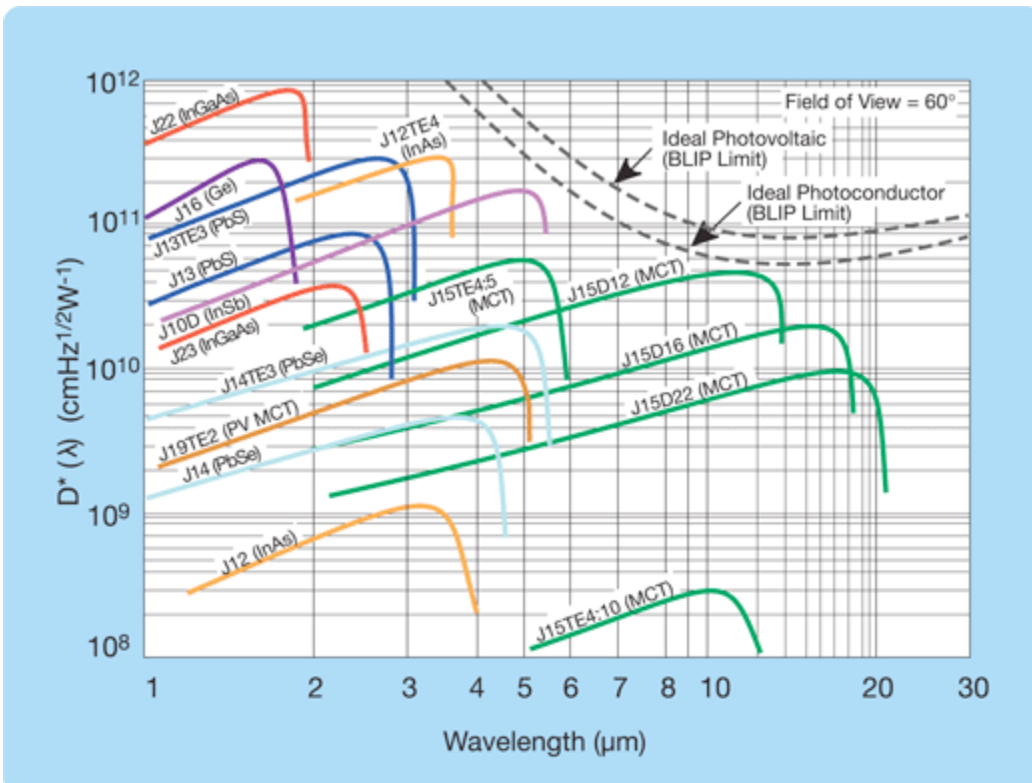


Figure 25: Suitable detectors graph

The graph consists of a few suitable detectors which could be used in the device. The detectors consist of MCT, PbSe and InSb detectors which have high sensitivity at 5 μm.

Unfortunately, all the detectors were far too expensive for just a simple household device. The quotation for every detector was more than £100 each. Therefore, there is a need for an alternative detector to fit into the budget given.

According to some research made, pyroelectric detectors are often used in spectrometers, they could work well in the prototype required.

The conclusion came to a pyroelectric device by Murata IRA-E700STO which costs around £2.07 for each detector. The advantage of these for a household device is that they are mass produced, and cheap.

Figure***: Murata IRA-E700STO pyroelectric detector

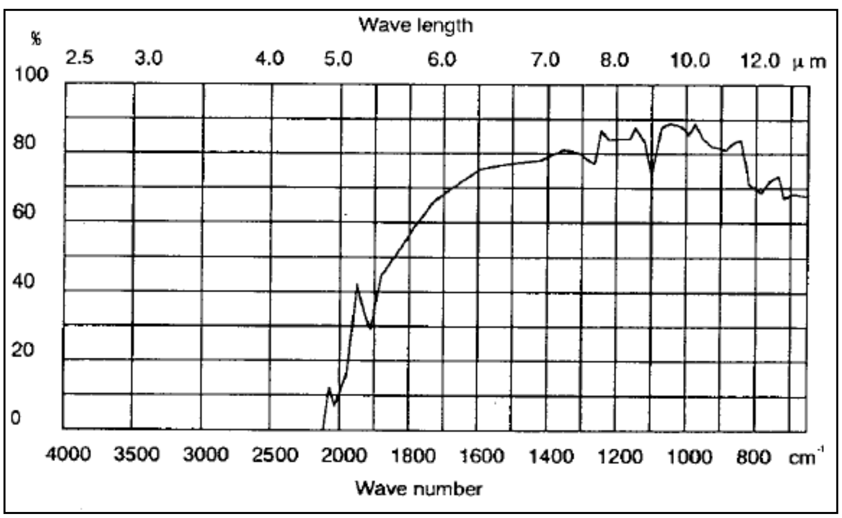


Figure 26: Response of the pyroelectric detector

Referring to Figure 26 above, the spectral response of the pyroelectric detector at 5 □□ is only about 10%. The detector chosen might not be the best ideal detector that we’re looking for. As the emitter is a high power source, it is assumed that it might not be a problem for the detector to respond to the emitter.

5.9 Working theory of the transmitter and detector

As previously mentioned, the emitter and detector needs to work at $2129 cm^{-1}$ as that's where the peak of Filter 4 lies.

5.9.1 Transmitter

The V8 by Vulcan Heat was chosen as the transmitter because the wavelength transmitted by the source was wideband wavelength. Therefore, it simplifies the whole process by not having to find a transmitter which only transmit signal around $4.7 \mu m$ of wavelength. The normal infrared diodes used in a normal infrared signal circuit differs from this transmitter because the wavelength range of a normal IR diode is much bigger compared to $4.7 \mu m$. There are transmitters which are able to transmit at the wavelength of $4.7 \mu m$, however, they are fairly expensive and the technology required from these infrared diodes would probably be lasers to achieve a much smaller and precise wavelength.

The V8 infrared light bulb transmitter is cheap, easy and reliable.

5.9.2 Detector

A pyroelectric detector was chosen as the detector for this device. Pyroelectric materials develop a charge in response to a change in temperature, which is much suitable as the transmitter is an infrared heat source transmitter. Pyroelectric detectors are widely used in motion detection applications for home security. The pyroelectric detector converts incident thermal radiation into an electrical signal. This conversion takes place in three steps the incident thermal radiation results in a change in temperature, altering the charge density on the electrodes. An electrical signal is generated by a preamplifier or impedance converter.

The pyroelectric detector would be a suitable choice of detector because it is compatible with the transmitter chosen. It's sensitive towards temperature changes and the transmitter is a heat source which varies in high temperature changes. In addition to that, this pyroelectric detector is able to detect infrared signal in the range of $4.7 \mu m$. It is also so much cheaper compared to the other detectors such as InAs, InSb or MCTs.

5.9.3 Detector Circuit

The detector was first built according to a circuit obtained from the datasheet of the detector. The first step taken in building the circuit was to measure the responsitivity of the detector and to check if it was really working.

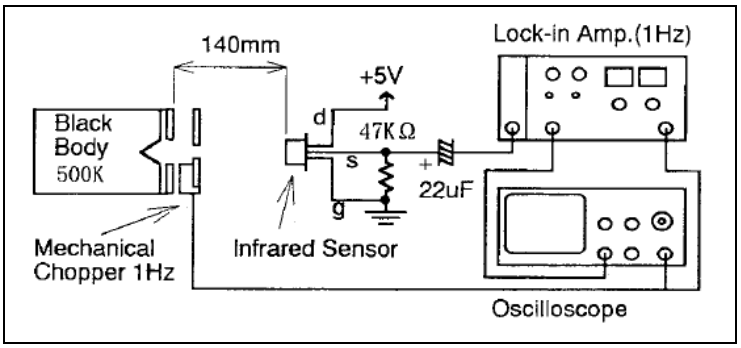


Figure 27: Basic circuit to measure detector responsitivity

As there's no Lock-in Amplifier (1Hz) in the labs, the circuit was only connected to the oscilloscope to see the changes when there's an infrared source placed in front of the circuit. The results from the following experiment shows a straight line waveform lying around GND. When the infrared source is placed in front of the detector, the straight line waveform toggles a little, but for just awhile, and it returns back to initial position. This means that there is a certain response from the detector.

After consulting Dr. Tony Wilkinson about the detector, it was found that the detector is sensitive towards changes in signal. Therefore, having a constant/static infrared source is not exactly ideal towards how the detector works. As the detector is sensitive towards changes, it explains the toggling of straight line waveform, meaning it responds towards the existence of the infrared source, and it returns to initial position as there are no more changes which occurred.

As there weren't much time left to proceed on the project, it was suggested to work with the detector provided. It wasn't impossible to build a working detector circuit based on the current detector, it just would turn up to be not the ideal way which it was meant to be.

5.9.4 Detector Circuit Schematic

The following detector circuit was found in the datasheet provided with the detector.

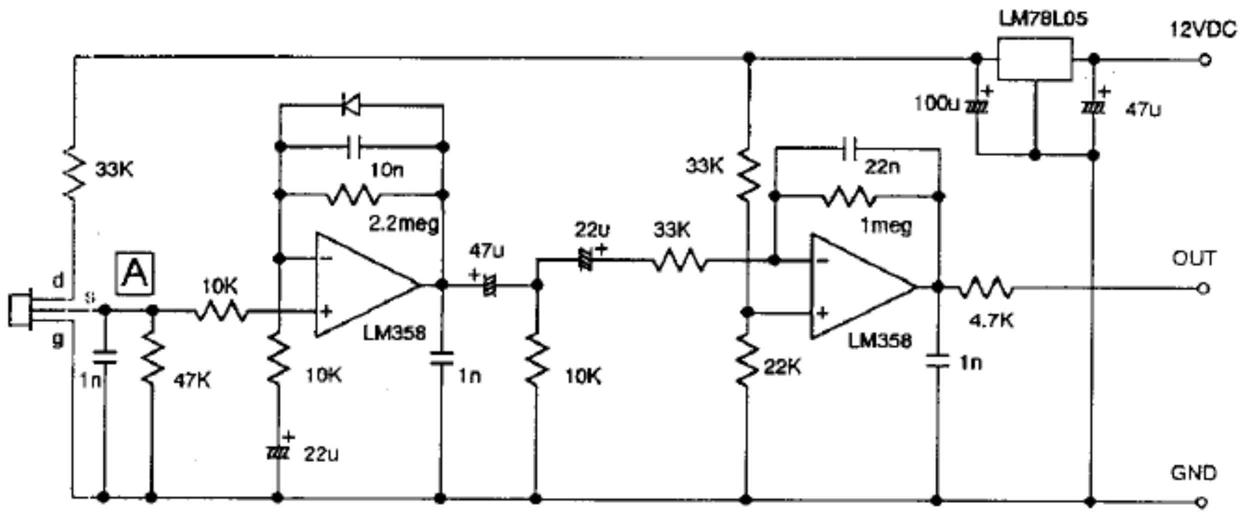


Figure 28: Detector circuit for measurement

The circuit was built as shown as the Figure 28 above.

The circuit works in the way that when it detects any signal, it will be connected to an operational amplifier to amplify the signal. The first operational amplifier that it's connected to acts to amplify the signal as the signal received may be very small. Therefore, the op-amp will amplify the signal so that the signal received could be noticed. Changes may be too small at times and it might not make a difference if the op-amp wasn't there. The second op-amp acts as a comparator, the gain in the second op-amp is determined by the resistors connected to it. The comparator will receive the signal from the first op-amp and compare the values between the signal and the pre-set gain of the op-amp. When the signal received is higher than the gain, the output will show a pulse signal. Otherwise, there will be no changes.

These outputs will be seen using an oscilloscope to test the circuit.

6.0 Working Theory Of The Detector Circuit

According to the circuit diagram,

The first amplifier is a non-inverting operational amplifier because the configuration of the circuit where the input voltage signal □□□ is applied directly to the non-inverting (+) input terminal which means the output gain of the amplifier becomes positive in value.

$$□□□□□□□ □□□□= □□□□□+1$$

$$=2.2□10□+1$$

$$=221$$

An operational amplifier is a DC-coupled high-gain electronic voltage amplifier with a differential input and a single-ended output. An op-amp helps produce an output voltage that is larger compared to the voltage difference between its input terminals. Therefore for the first amplifier, the gain is 221. The amplifier is needed because the sensor output might be weak and too small for any kind of observation.

The second amplifier in the circuit acts as a comparator circuit, it is used to compare two voltages. When one is higher than the other, the comparator circuit is in one state, and when the input conditions are reversed, the comparator output switches to another state.

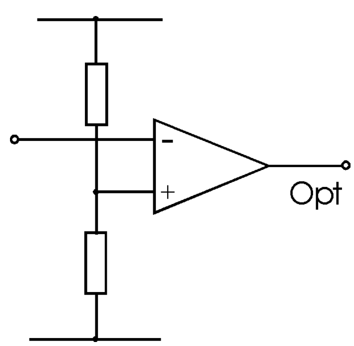


Figure 29: Circuit for a basic operational amplifier comparator circuit

Assuming the resistors of $33k\Omega$ and $22k\Omega$ are the resistors used to set the reference voltage to be compared to. Therefore, the calculations are as follows.

Using the Voltage Divider formula,

$$V_{ref} = \frac{R_2}{R_1+R_2} \times V_{CC}$$

$$= \frac{22k}{22k+33k} \times 12$$

$$= 4.8V$$

From the calculations above, the V_{ref} is the voltage reference of the comparator circuit. Meaning, it will compare the voltage from the detector and compare it to the voltage reference which happens to be 4.8V. If the DC signal from the detector circuit is not larger than 4.8V, the comparator circuit will not produce an output.

The purpose of the comparator op-amp in the circuit aims to detect the difference between two plastic materials: recyclable and non-recyclable. According to experiments, different materials will trigger the receiver at different varying voltages, for example, one material might be higher and another material is lower. Based on this distinguishable feature, a threshold level between two peaks of the sensor responses towards various materials and comparator output pulses could be determined. That’s how the detection circuit works as a material evaluator.

The circuit built based on Figure 28.

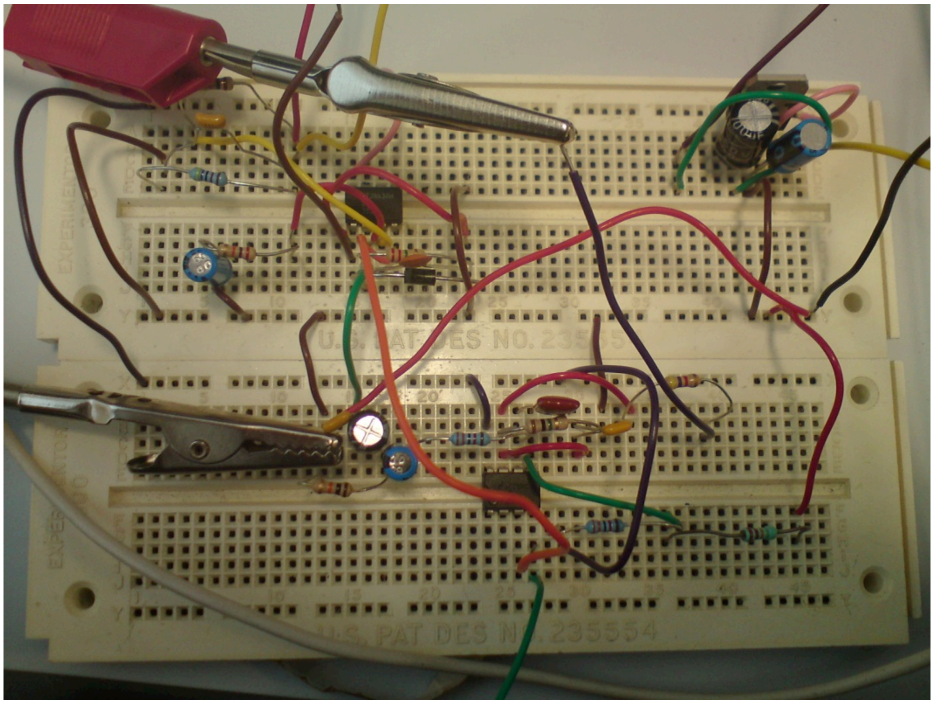


Figure 30: Detector circuit (Figure 28)

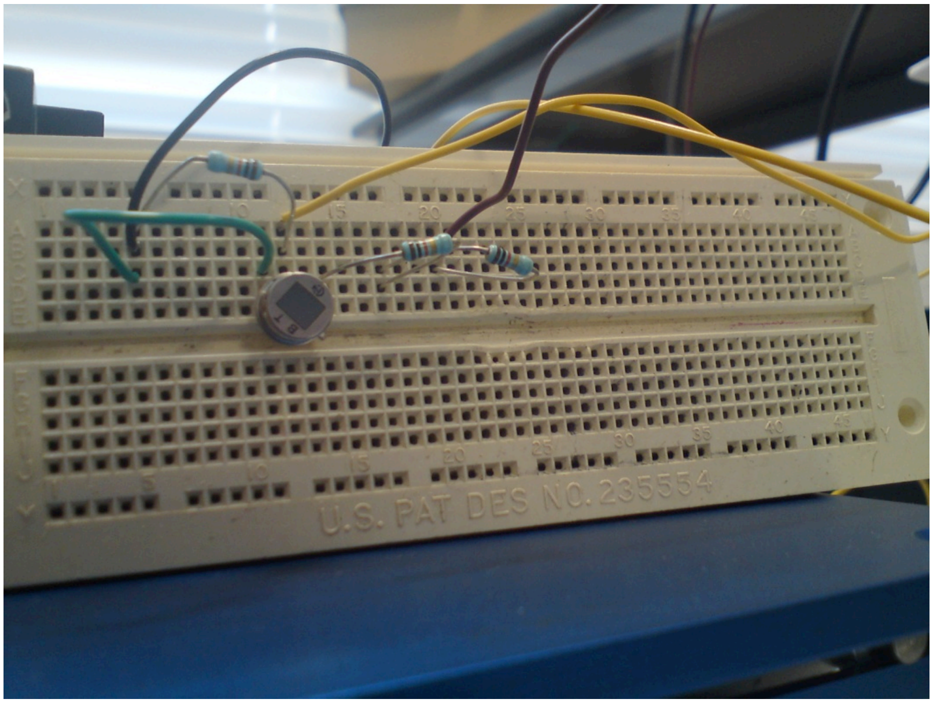


Figure 31: Detector circuit (Figure 28)

Firstly, simple tests were carried out to check the responsitivity of the circuit and detector, also to see if the circuit is actually working.

Test 1: When there's no infrared signal (Infrared Light is OFF)

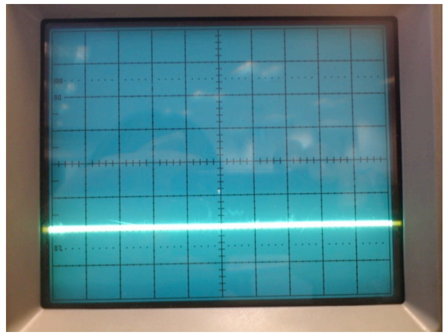


Figure 32: Results from Test 1

As seen from Figure 32 above, the straight line waveform changes from GND to negative when the detector circuit is turned on. The waveform remains as negative is probably because of the non-inverting amplifier connected. The straight line waveform remains in the same position as it does not detect any infrared light.

Test 2: When infrared signal is turned on (Infrared Light is ON)

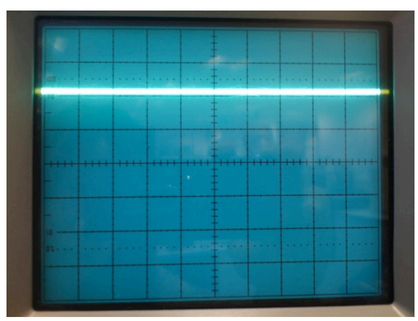


Figure 33: Results from Test 2

The infrared light source was turned on and placed in front of the detector during the Test 2. After some time, the straight line waveform which was previously on the bottom changed from bottom to top, and remains on top as long as the infrared source is still ON. The response of the detector is quite slow as the time taken for the change to occur was not immediate. This would be another problem with the detector.

As from the Test 1 and Test 2 conducted, it could be determined that when the infrared signal is off, the detector does not detect anything and remains as it is. When the infrared signal is on, the detector will detect the infrared signal transmitted and therefore making a change as seen on the oscilloscope.

However, there might be noises and environmental temperatures which affects the readings on the oscilloscope. That is because there will be random short term pulses generated when there were no changes during the tests.

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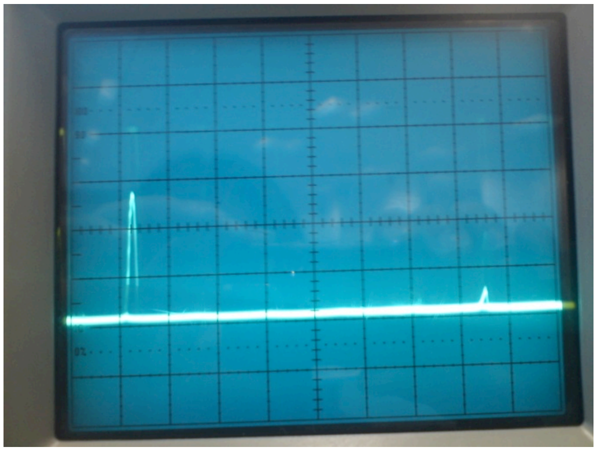

Figure 34: Noise which affects the circuit

As seen from the Figure 34, there will be random short term pulses which are generated even when there were no changes made. The pulses would probably be caused by the noises around the environment. For example, it might be detecting the signals from the normal lights in the labs as the circuit is not covered in a dark area.

Therefore, a box is placed on top of the detector circuit to reduce the noise received from the working environment. The box is used to create a darker environment surrounding the detector and also to block the transmittance of the surrounding lights towards the detectors.

6.1 Experiments With Different Plastics Materials

As the detector is working fine from the previous tests conducted, the next step towards the progress was to test the circuit with the plastic samples placed in between the source and detector. The assumption made during the experiments was that the recyclable plastics were able to transmit infrared signal through and towards the detector while the non-recyclable plastics were not able to transmit any infrared signal towards the detector.

6.1.1 Polyethylene Terephthalate (PET)

Figure 35: Water bottle PET sample

PET is one of the recyclable plastics, the most common examples of PET would be water bottles. The water bottle was cut into small pieces of PET and placed in front of the detector. The responding results of the test was that the PET sample allowed the infrared signal to transmit towards the detector and showing a change in signal from the oscilloscope. It took quite some time for the detector to respond.

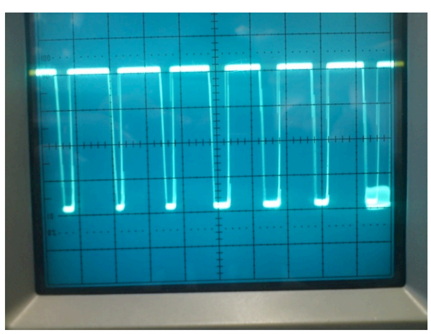

Figure 36: Results from the PET sample

The signal changes from time to time, it does not stay on top consistently.

6.1.2 Polystyrene (PS)

Figure 37: White Cup PS sample

Polystyrene is one of the non-recyclable plastics, there is a number #6 labeled at the bottom of this cup. A small piece of the cup was placed in front of the detector, considering it's not a recyclable plastic. There would be no transmittance of light towards the detector.

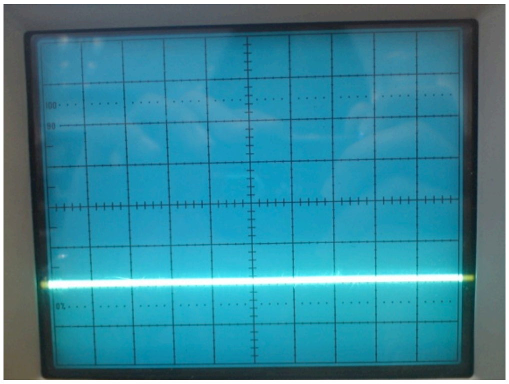

Figure 38: Results from PS sample

The oscilloscope shows the results as seen from Figure 38, the detector is not detecting any infrared signal from the source. This shows that the plastic is not recyclable as there's no transmittance of infrared signal towards the detector.

6.1.3 High Density Polyethylene (HDPE)

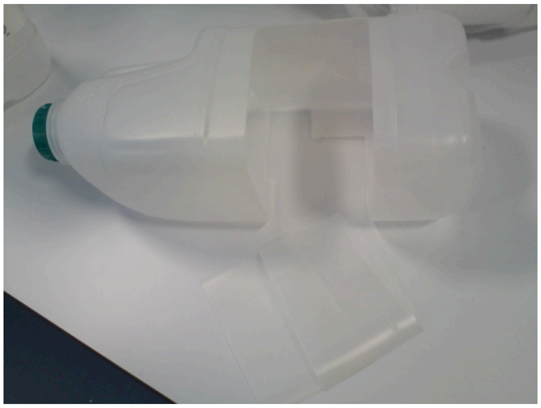

Figure 39: Milk bottle HDPE sample

The most common examples of HDPE would be milk bottles, they are recyclable plastics. The same test was repeated for this sample where it is placed in front of the detector and the corresponding readings on the oscilloscope is observe.

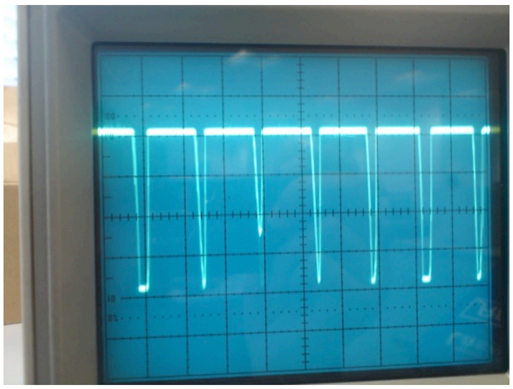

Figure 40: Results from HDPE sample

The results showed that the HDPE sample was able to transmit infrared signal to the detector. The response of the HDPE sample was much faster compared to the PET sample, considering both of them are recyclable plastics.

6.1.4 Polypropylene (PP)

Figure 41: Black box PP sample

Polypropylene is not a recyclable plastic, therefore the results shown on the oscilloscope was the same as Figure 41 (PS) where there are not transmittance of infrared signal. Due to the fact that the color of the plastic is black, it may as well have absorbed all sorts of infrared signal.

6.1.5 Plastic bags

Figure 42: Plastic bag sample

As we know, plastic bags are definitely not recyclable plastics. The results shown on the oscilloscope was that it had no transmittance of infrared light towards the detector.

The assumption made for this experiment was that non-recyclable plastics were not able to transmit infrared signal while the recyclable plastics were able to transmit infrared signal so that it could be detected by the detector. There is no specific proof of this theory, and therefore the system is not reliable.

The circuit which was built could be considered as working properly.

6.2 Alternative results

As previously mentioned from the experiments of obtaining spectra, Filter 4 is a band in the middle of the spectrum appeared where all the recyclable plastics lay. Therefore, Filter 4 would be most suitable used to distinguish between the recyclable and non-recyclable plastics.

With the exact same circuit as Figure 28 above, the circuit was tested out again with the help of a filter. The spectral filtering is used to select or eliminate information from an image based on the wavelength of the information. Therefore, with the use of Filter 4, it will eliminate the wideband wavelength from the transmitter, allowing it to focus only on 2000 wavenumbers.

Test 3: Transmitting and receiving between transmitter and receiver without filter in between

Transmitter Condition	Voltage (V)
OFF	0.94
ON	1.43

Table 7: Results from Test 3

Same as the results from Test 1, there is a DC signal change when the transmitter is placed in front of the detector. The increase of voltage means that the detector is receiving infrared signal from the transmitter. Therefore, it can be confirmed that the circuit is working properly.

Test 4: Transmitting and receiving between transmitter and receiver with filter in between

Transmitter Condition	Voltage (V)
OFF	0.94
ON	0.94

Table 8: Results from Test 4

With the filter in between the transmitter and receiver, the filter will prevent the infrared signals from other wavelengths from passing through it. In the results obtained from Test 4, it shows that there's no change in voltage for when the transmitter is ON or OFF. From the Test 4, it means that the detector is not detecting any infrared signals from the transmitter.

After realizing that the filter might not be the ideal filter for the whole circuit, experiments were continued without the use of the filter.

Test 5: Measuring voltage change for each type of plastic

Plastic Material	*1*	*2*	*2−1*
Water Bottle PET	0.63	1.23	0.60
Black Polypropylene	0.65	1.20	0.55
Polystyrene White Cup	0.77	1.13	0.36
Milk Bottle HDPE	0.85	1.08	0.23
Transparent Polypropylene	0.78	1.12	0.34

Table 9: Results from Test 5

Although without the use of the filter, there are no meaning from the Test 5 conducted. However, this Test 5 would be the suitable test to distinguish between recyclable and non-recyclable plastics, with a filter that actually works.

The *1*in the Table 9 above is the voltage when the transmitter is turned off, and *2* is the voltage after the transmitter is turned on with the plastic material in front of it. While the subtraction between *2* and *1* will measure the total voltage change before and after the transmitter is turned on.

The results obtained are in the form of the change of voltage. The amount of transmitted light depends on the voltage change of each plastic material. The higher the voltage change, the more transmittance of light through the material. Therefore, from the results obtained as from Table*** above, the highest voltage change would be the water bottle PET, this means that the PET allows a large amount of infrared signal transmit through it. While on the other hand, the milk bottle HDPE only allows 0.23V transmit to the detector, the assumption made here is that the HDPE absorbed the infrared signal and therefore the voltage change is smaller compared to the other materials.

With a suitable filter that works with the circuit, the concept of the expected data should be the same as the test above. The data measured can then be compared with the data obtained from the spectra analysis.

7.0 Discussion

From the Chapter 6.1, 'Experimenting With Different Plastic Materials', the assumption made was that when there's infrared signal transmitting through the plastic, hence the plastic is recyclable. Otherwise, the plastic is non-recyclable when there's no infrared signal received at the detector.

The experiments were carried out by testing all the different types of plastic materials gathered. The plastic was placed in between the detector and the transmitter and the results were displayed on the oscilloscope. As shown from the results achieved, the recyclable plastics which are PET and HDPE, are able to transmit infrared signal towards the detector while the non-recyclable plastics such as PP, PS and plastic bags are not able to transmit any sort of infrared signal.

The experiments carried out and methods used may be able to distinguish the sample used, but there's no guarantee that it is able to distinguish any other different types of plastics of the same kind. The problem with this method is that there's no particular filter involved. According to the spectra of plastics obtained, a non-recyclable plastic does not mean that it is not be able to transmit any infrared signal completely in a given wavelength, and a recyclable plastic sometimes absorbs the infrared signal at certain wavelengths and there will be no transmission of infrared signal. There is no proof of the method actually works.

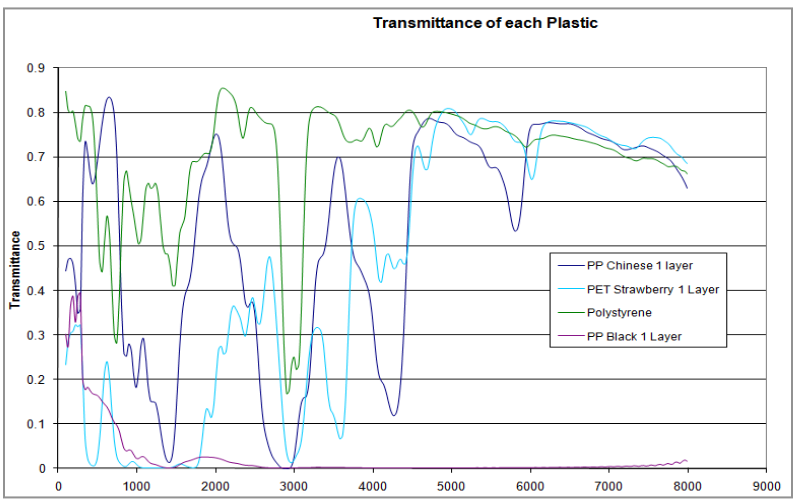

Figure 43: Spectra for different plastics (recyclable and non-recyclable)

As can be seen from Figure 43 above, there are 4 different plastic spectrums in it, both recyclable and non-recyclable. Take PET as a recyclable plastic example, there are a few transmittance peaks on the spectra, and PET is not transmitting or transmitting very little signal between 1000 and 2000 wavenumbers. As for PP Black, it's a polypropylene plastic which is black in colour. The transmittance of infrared signal between 0 to 1000 wavenumber is deteriorating, but there's transmittance of infrared signal in the beginning although PP is not a recyclable plastics.

Therefore, for that matter, the assumption has been rejected and the method clearly does not work.

After realizing the mistake made in that chapter, a filter was implemented into the circuit. The filter used was the same filter used during the experiments of obtaining the spectra.

The reason for spectral filtering is used to select a certain wavelength of information and eliminating the rest. This filtering is usually effected by passing light through a glass or plastic window that has been specially treated to transmit or absorb/reflect some wavelengths. Since the light entering a sensor will have a spectral distribution that depends on both the illumination source's spectral characteristics and the reflectance of the illuminated scene, using a filter to select image regions with known spectral properties can help extract the desired information.

For that matter, a few filters have been provided and tested out to find the most suitable filter that could be used. As a conclusion, Filter 4 has been chosen to be the best filter that will be able to distinguish between recyclable and non-recyclable plastics.

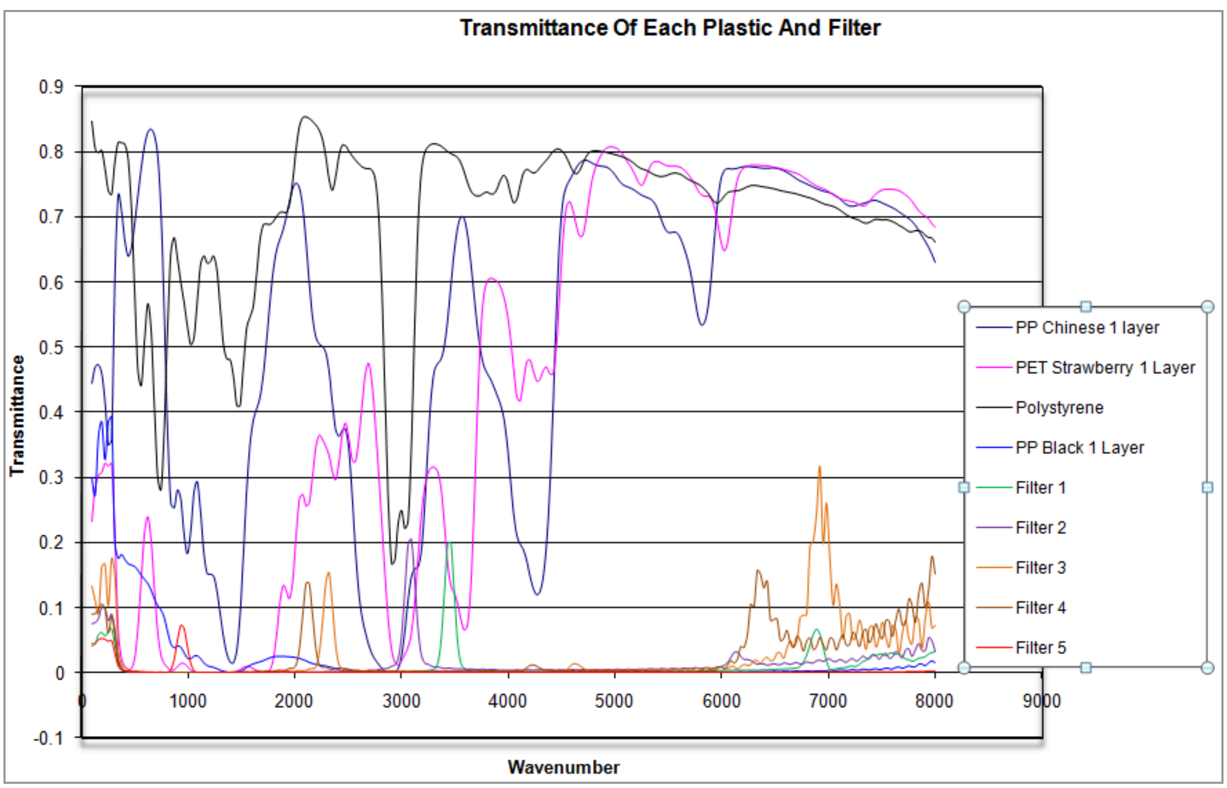

Figure 44: Transmittance of each plastic and filter spectra

All filters have each of their own transmission peaks as seen from the Figure 44 above, Filter 4 was chosen because the transmission peak at $2129cm^{-1}$ wavenumber is around 0.14. At $2129cm^{-1}$ wavenumber, there is clear separation of all the plastic materials, the transmittance are all different and therefore it could be easily distinguished.

Another reason why Filter 4 is chosen is because the detector cuts off at around $2200cm^{-1}$, which means at any wavenumber higher than $2200cm^{-1}$ wavenumber, the detector will not be able to detect any infrared signal. Therefore, Filter 1, 2 and 3 are not suitable as their transmission peaks are all above $2200cm^{-1}$ where the detector will not be able to detect anymore.

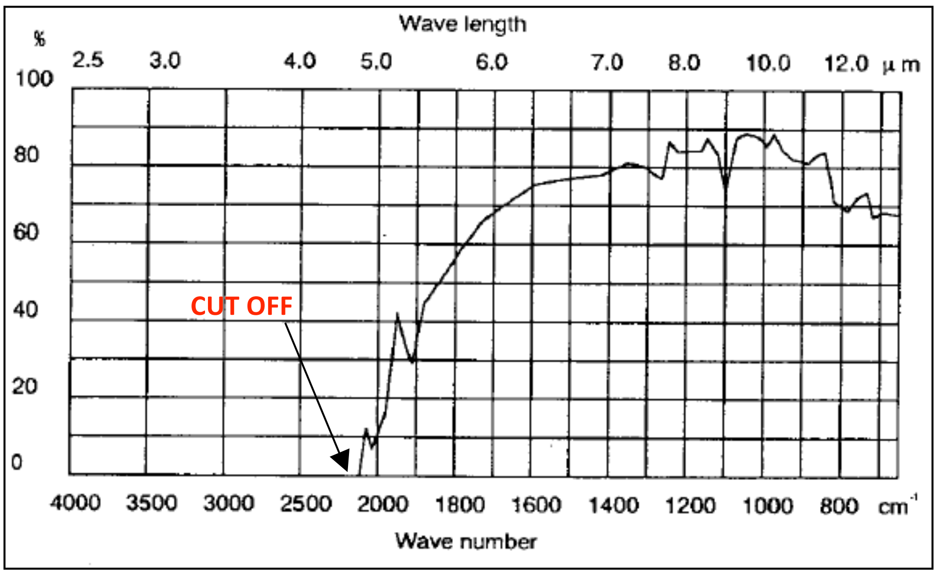

Figure 45: Cut off wavelength of the detector

The cut off wavelength is probably caused by the window installed on the detector which restricts the detector from being able to detect infrared signals from any wavelength higher than $2200cm^{-1}$ wavenumber. As it can be seen from Figure 45 above, the sensitivity of the detector is decaying as the wavenumber increases and it completely cuts off in the end.

Filter 5 is also suitable to be used as a filter because the transmission peak lies at $956cm^{-1}$ wavenumber, and the detector is 85% sensitive at that wavenumber (Figure 44). However, the transmittance of Filter 5 is only 0.067 which happens to be quite small. Other than that, there is no clear separation of the different plastics at that wavenumber, which will lead to making it harder to distinguish between materials. Therefore, comparing Filter 4 and Filter 5, Filter 4 would be a better choice to be used as the filter.

The circuit was tested out again using the filter in between of the transmitter and the detector as done in Test 3 and Test 4 above. The detector does not show any changes once the filter was placed in front of the transmitter. Therefore, it means that the filter has prevented any infrared signal from transmitting through to the detector.

There can be 2 assumptions on why this problem occurred:

1. The detector cut off wavelength is around $2200cm^{-1}$, and the wavelength of interest lies on $2129cm^{-1}$, it could probably be the problem with the detector as the cut off wavelength is too close to the wavelength of interest causing it to not be as sensitive and only very little transmittance of infrared light was passed through but it may be too small to be detected. Due to the filtering window on the detector, it causes the sensitivity to decay as the wavenumber increases.

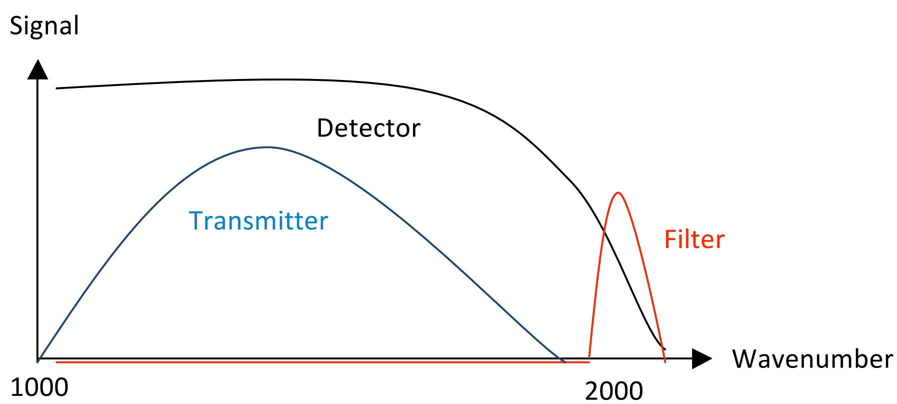

Figure 46: Signal vs wavenumber graph

2. Referring to the Figure 46 above, it's a signal vs wavenumber graph between the detector transmitter and filter. The transmitter and detector are working with each other, meaning that between 1000 and 2000 wavenumber, the transmitter and detector are able to receive signal between each other. The wavenumber 1000 to 2000 was taken as an example because the detector is sensitive there, but the filter does not transmit at all during that wavenumber. So we could assume that the detector and transmitter are able to transmit and detect between 1000 and 2000 wavenumber, so if the filter cuts in, there will be no detection. This is just an assumption, to argue that the filter might not be the ideal filter as the circuit is working just as fine before the filter was added into it.

Based on the discussion above, it can be clarified that the circuit is working properly. However, due to not having the ideal components, the device is still not reliable as a plastic distinguishing device.

The next wise step that could be made would be to verify if the assumptions made are considered qualified as a test signal. A test signal is defined in terms of different sensitivity towards different materials. The assumption made is using the ideal filter, we will be able to receive and detect infrared signal and therefore we could check and make sure that the signal received within the wavenumber chosen, which is $2129cm^{-1}$ is the correct and accurate signal. Unfortunately, the filter currently used during the progress of the whole project is not compatible with the circuit and therefore it puts a halt to this project.

Another good suggestion in the verge of improving the project would be to get a detector which can detect within the range of 3000 and 4000 wavenumbers. Filter 1 and Filter 2 could be suitable for ranges between 3000 and 4000 wavenumbers. Due to the fact that the filtering window is on the detector, it completely cuts off at $2200cm^{-1}$ wavenumbers. It may be a good idea to remove the window and try again.

As for the Test 5, Test 5 would be the correct method use to distinguish plastic materials with an ideal filter. It is based on the changes of voltage, if transmittance is high, the voltage change at the receiver should be high as well. The results obtained from here will then be compared to the spectra obtained from the experiments. For example referring to Figure 44, at $2129cm^{-1}$, Polystyrene should have the highest transmittance at this wavenumber, followed by Chinese (Transparent) PP, PET, and lastly Black PP. It should be compatible with the results obtained from the voltage change where Polystyrene should have the highest voltage change followed by Chinese PP, PET and Black PP. If this experiment could work just as fine, it then can distinguish between different types of plastics.

7.1 Factors which may affect the plastic sorting process

While the recycling of plastics from bottles is widely practiced commercially, the recycling of plastics from durable goods such as automobiles, computers and electronic equipment, appliances, building and construction, and even sporting goods is more recent interest as the recovery of these products becomes more commonplace.

The few factors that may affect the plastic sorting process are as follows.

- Shapes and sizes of the plastic
  The wide variety of shapes and sizes of plastics implies that parts of the plastics may be difficult to “singulate” on a traditional conveying system. It also makes probing with a remote sensing device more difficult because the orientation of the surface and the distance to the surface with respect to the probe may change significantly with each part.

- Average wall thickness of plastics
  The thicker walls and part opaqueness, make energy transmission through the part much more difficult. It is assumed that the thicker the layer of plastic is, the more absorption of infrared light from the plastic. Therefore, it may affect the results obtained.

- Plastic opaque and often contain carbon black
  Carbon black absorbs much of the radiation from traditional spectroscopic identification techniques, making it difficult to obtain information from the underlying host polymer.

- Paint and coatings on plastics
  Paint and coatings can cause property reductions in some recycled plastics from stress concentrations created by the coating particles. The level of potential property reduction depends on the combination of the type of plastic substrate, coating type and coating thickness.

All these factors may affect the process of sorting plastics and may have a defect by distinguishing the wrong types of plastics. Therefore, a slower identification technique could be economically feasible for plastic which has these factors.

7.2 Other technologies used for plastic sorting

Technology	Advantages	Disadvantages
MIR	• Fundamental vibration yield "fingerprints" – increased accuracy and information • Can measure black plastics • Proven technology	• Very surface sensitive • MIR fiber optics are limited in range, expensive and fragile • Remote sensing difficult • Commercial MIR instruments slower than NIR instruments
NIR	• Commercial units available • Can use "normal" fiber optics • "Portable" units already used for QC • Fast and can be done without contact • Some have no moving parts (rugged)	• Limited information in this range – overtone vs. fundamental peaks • Carbon black absorbs and scatters highly at NIR frequencies, making dark plastics difficult to probe
SWNIR	• Low cost equipment • Very small instrument with fiber optics • No moving parts (rugged)	• Only limited polymers (and colours) can be detected • Still somewhat developmental
Raman	• Can be fast and remote is possible • Fiber optic probes possible • Spectral detail similar to MIR	• Fluorescence of black pigments • Lasers expensive
Pyrolysis and Plasma Techniques	• Could obtain very accurate identifications • Could be very fast • Addictive ID possible	• Sampling could be difficult • Polymer degradation questions • Still in laboratory stage
Triboelectric	• Only known true hand-held device • Completely portable and easy to use • Fast response • Inexpensive	• Very limited in number of polymers • Can be sensitive to moisture and surface contamination • Still developmental

Thermography	• Remote probing possible • Some coatings may not be a problem • Can be very fast	• "Signatures" of many polymers very similar • Still developmental
X-ray	• Can detect heavy atoms additives and components, like Cl, Br, Cd, Pb etc. • Fast and remote • Proven technology	• Can't distinguish between different polymers • Expensive • Radiation safety issues

Table 10: Comparison between plastic technologies (Michael B. Biddle)

8.0 Hardware Design

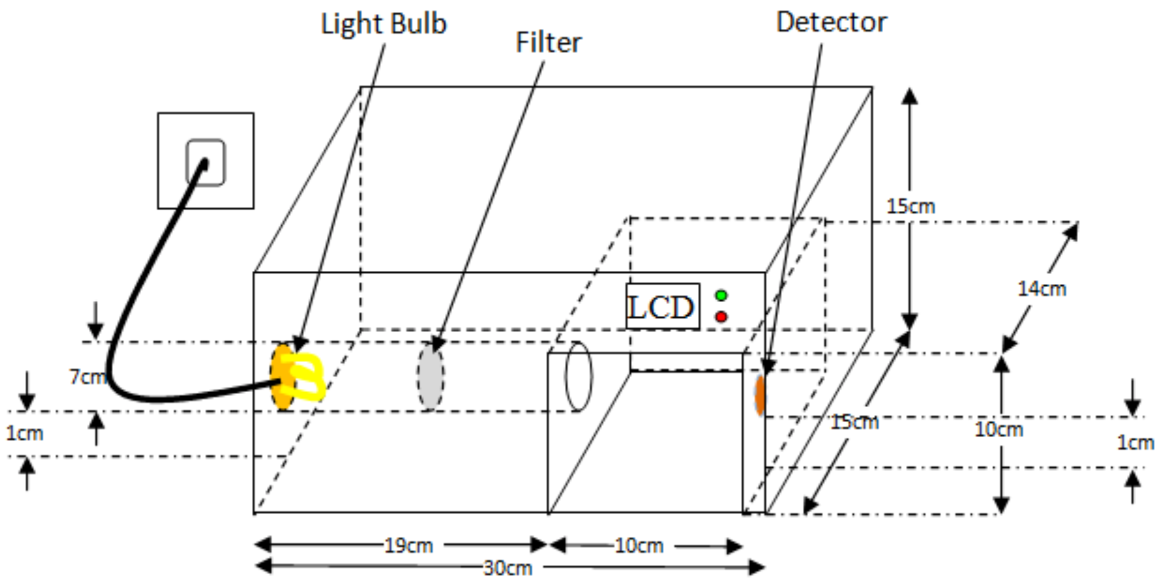

Figure 47: Draft Model Design

The Figure 47 above shows the draft model design of the electro-optical device. The design consists of the infrared light bulb, filter, and also the detector. The tube surrounding the infrared light bulb allows the infrared signal to be focused towards the filter and the detector, avoiding any dispersion of any infrared signal transmitted from the light bulb. The space in the middle of the device is where the plastic samples will be placed for distinguishing. Ideally, there will be an LCD display and two LEDs to display results for the user to see.

The best suitable material to build this draft model design would be the Acrylonitrile Butadiene Styrene (ABS). The reason why this material is chosen is because it is a common thermoplastic which has a high melting point. The infrared light bulb is a heat source light bulb, therefore, the material built around it needs to be able to withstand the heat produced.

9.0 Budget

This project was a hardware implementation project, therefore, the cost for this device would be the components needed to build the detector circuit and also the infrared light source.

In the progress of the project, the cost to build the device is as follows:

Component	Cost (£)
Infrared light source (V8)	10.36
Pyroelectric Detector	2.07
Resistors	Free from lab
Voltage Regulator	0.29
Operational Amplifiers	0.58
Capacitors	Free from lab
Prototype	50.00 (estimate)
Total Cost	63.30

Table 11: Project Budget

As a low cost plastic sorting device, the cost to build the device would be estimated to be around £63.30 The objective of the device is to be placed in household area where the public can use it to distinguish plastics at home before bringing it to the recycling center. Therefore, the cost to build the device is not expensive, there would be a market value for the device if it was mass-produced.

The device is simple, easy, and efficient. It would be useful for the public to use so they would be able to distinguish different types of plastic correctly. This would be easier for the recycling organizations as they do not have to sort the plastics again by themselves.

In addition to that, with the use of the device, we could distinguish between recyclable and non-recyclable plastics. When we know that the plastic is not recyclable, we could practice the habit of reusing the plastic instead.

10.0 Gantt Chart

Tasks	Week									
	1	2	3	4	5	6	7	8	9	10
Research And Study About Project	■									
Find Suitable Method To Be Used		■	■							
Experiments To Obtain Required Plastic Sample Spectra Using Spectrometer		■	■	■						
Study Spectra And Decide On A Way To Distinguish Recyclable and Non-Recyclable Plastics			■	■	■	■				
Building Detector Circuit				■	■	■	■			
Run Tests And Experiments On The Detector Circuit					■	■	■	■	■	■
Placing Plastic Samples Into Practice With The Circuit								■	■	■
Gather Data Required									■	■
Dissertation									■	■

Table 12: Gantt Chart

11.0 Conclusion

Plastics cannot be distinguished by sight alone, therefore a device to help distinguish the plastics for recycling purposes would be useful. The NIR spectroscopic method is currently being used in recycling companies to quickly sort bottles according to polymer type in plastics recycling operations. The proposed project is to develop a simpler device using similar method so that the public can help sort out between plastics. The method is based on the observation that a certain peak in the NIR absorption spectrum shifts according to each polymer's spectra. Once each different plastic has been sorted out individually, the recycling process would be more efficient. Another factor is with the presence at a very low level of a different polymer, it is able to destroy the uniformity and utility of the recycling materials. However, there might be a few factors that disrupt the NIR process, which is based on the color or thickness of the plastics. Dark colors may produce inaccurate wavelengths due to the inaccurate absorption of light. On the other hand, the thickness of the plastic material may also lead to more absorption of light. Hence, there might be certain specifications required before the plastic sample can be placed into the device.

From the experiments conducted, I found out that to find the ideal detector or infrared light source is not an easy task to do. There are a lot of considerations needed to make before deciding on the emitter and detector to be used. The infrared light source in the form of a light bulb is powered at 60 Watts, which may be too much power consumption. Therefore, it is advisable to get a lower power consumption infrared source. As for the detector, the detector used is not an ideal one as it is sensitive towards changes rather than a static source. These changes need to be made in order to build a successful device to distinguish plastics efficiently.

The further research on this project can include automated image analysis to the identification and extraction of recyclable plastic bottles. The development of this automatic sorting system uses available image processing techniques where images of the bottles are digitized, pre-processed with standard filter algorithms, and then analyzed to extract meaningful features of the objects in the image. The classifying process also requires the comparison of the extracted features with those present in a database. (Edgar Scavino et al., 2009)

12.0 Future Work

Research is needed into the economics of the commercially available technologies. As for my project, the future work that could be included into it is to develop the prototype for the device. That would be the relevant step after getting the emitter and detector to work efficiently.

Other than that, as previously mentioned, the emitter and detector used during the process of this project were not ideal components. It might be better to obtain detectors which can detect in the region of the wavelength of interest. There are detectors available for such purposes but they are just way out of budget. Maybe there will be detectors next time which are suitable and affordable for this device.

As a step forward for the device, we could include a better way of displaying results on the device. For example, installing a LCD screen on the device to tell the user if the plastic is recyclable or non-recyclable. This would be easy for the user as they can read the display on the LCD screen. It would be more user-friendly and users would find it convenient to use.

Other than that, LEDs diode could be added to the detector circuit. For example, the green LED will be ON when plastic is recyclable and the default red LED would turn on if plastic is non-recyclable.

These are the basic ideas which could be added into the device to make it more efficient.

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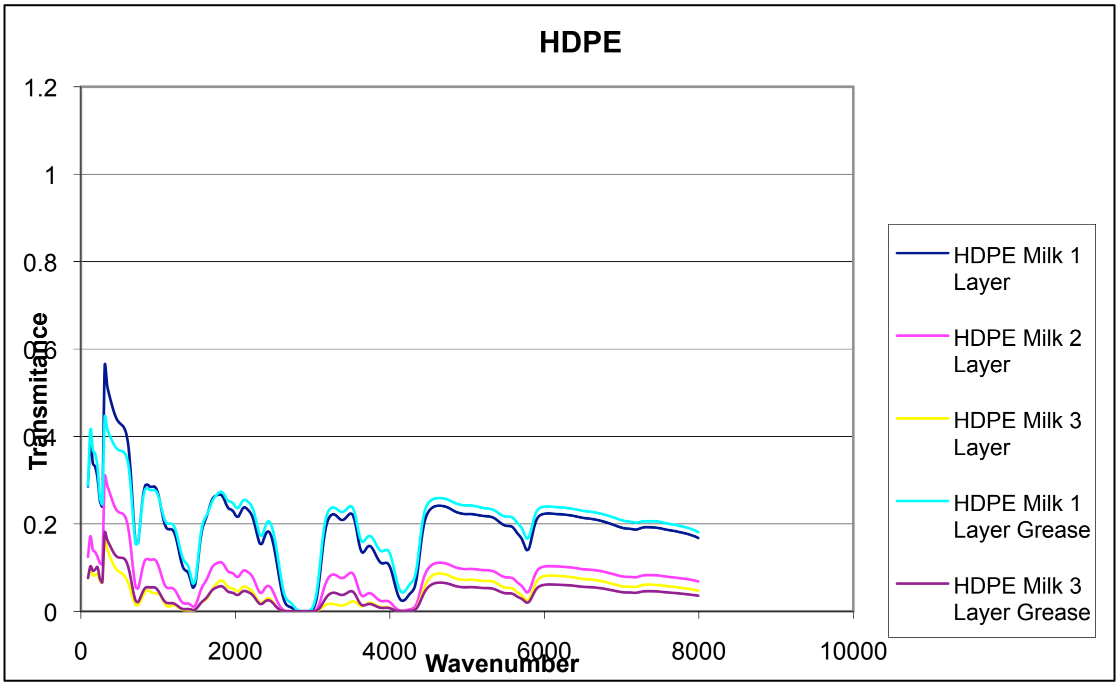
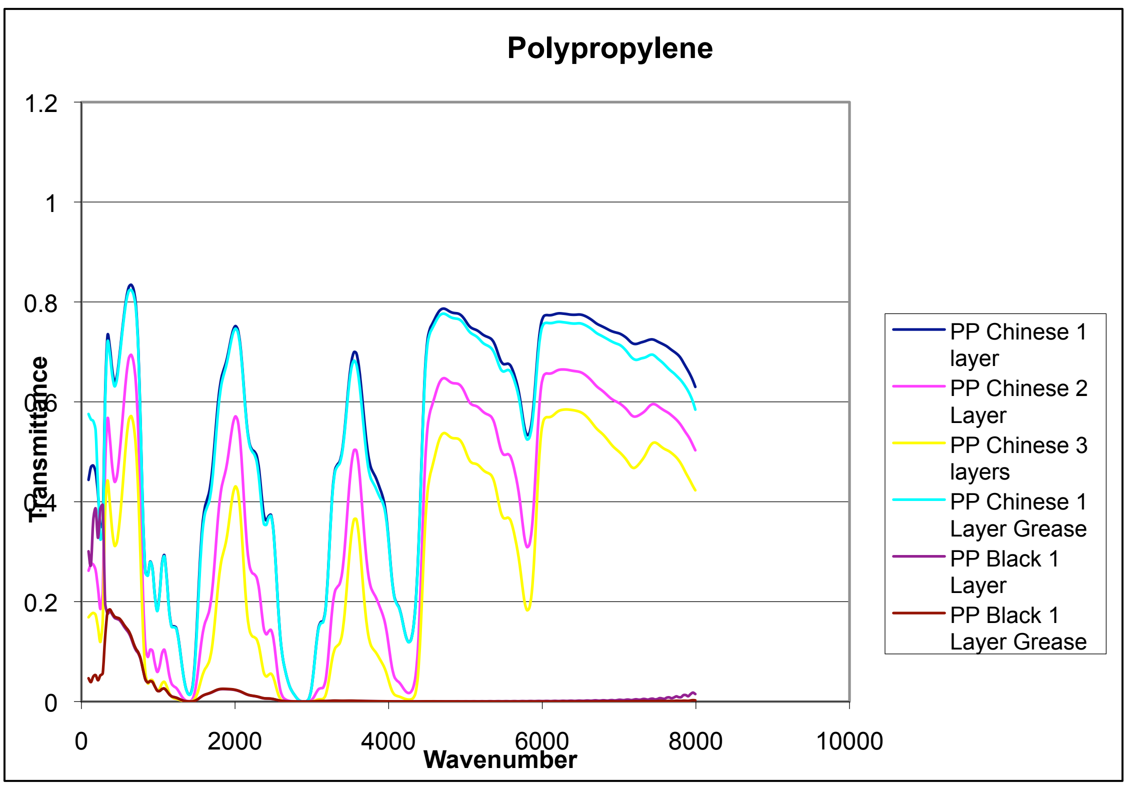
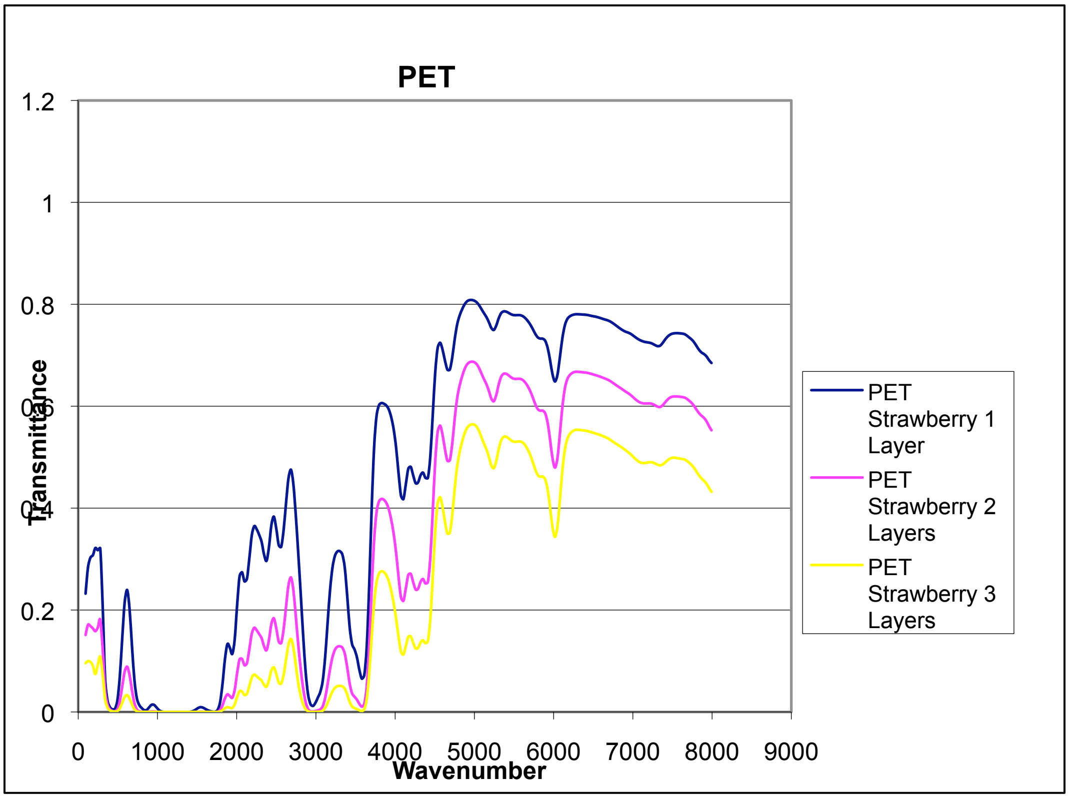
14.0 Appendix






PET
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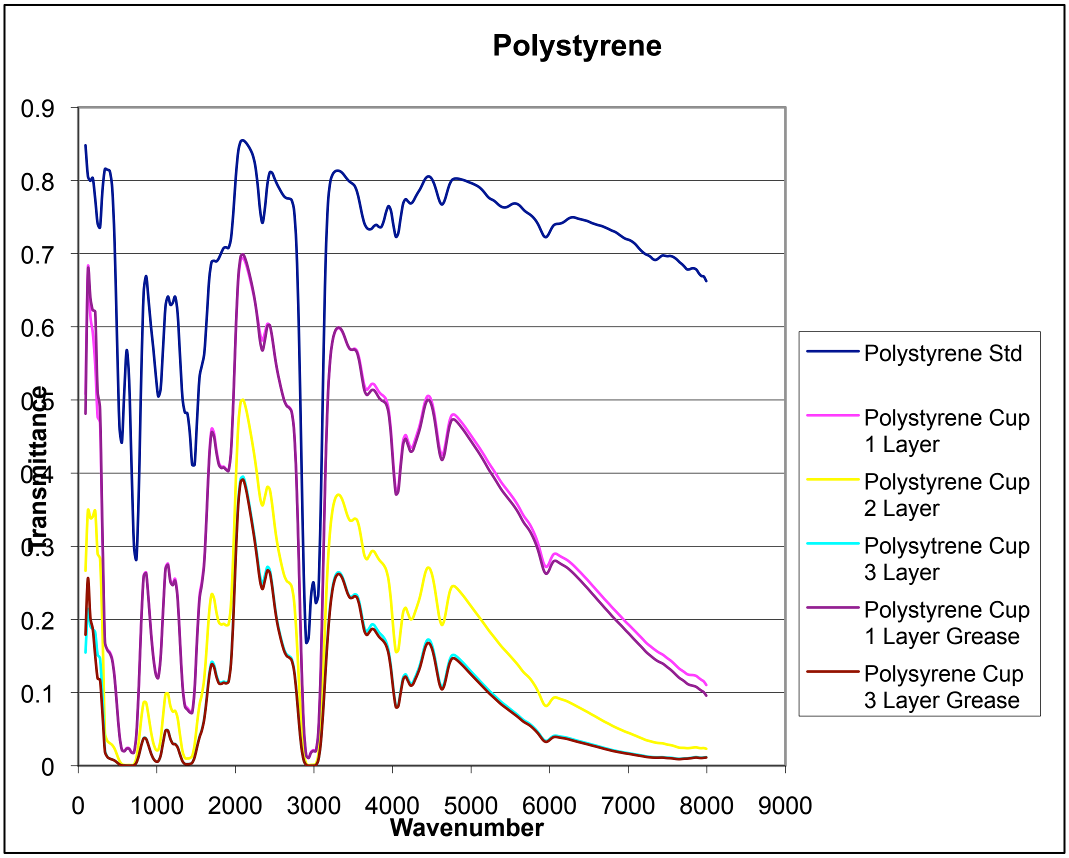
1
0.8
0.6
0.4
0.2
0
Transmittance
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Wavenumber
PET Strawberry 1 Layer
PET Strawberry 2 Layers
PET Strawberry 3 Layers


Polystyrene
Transmittance
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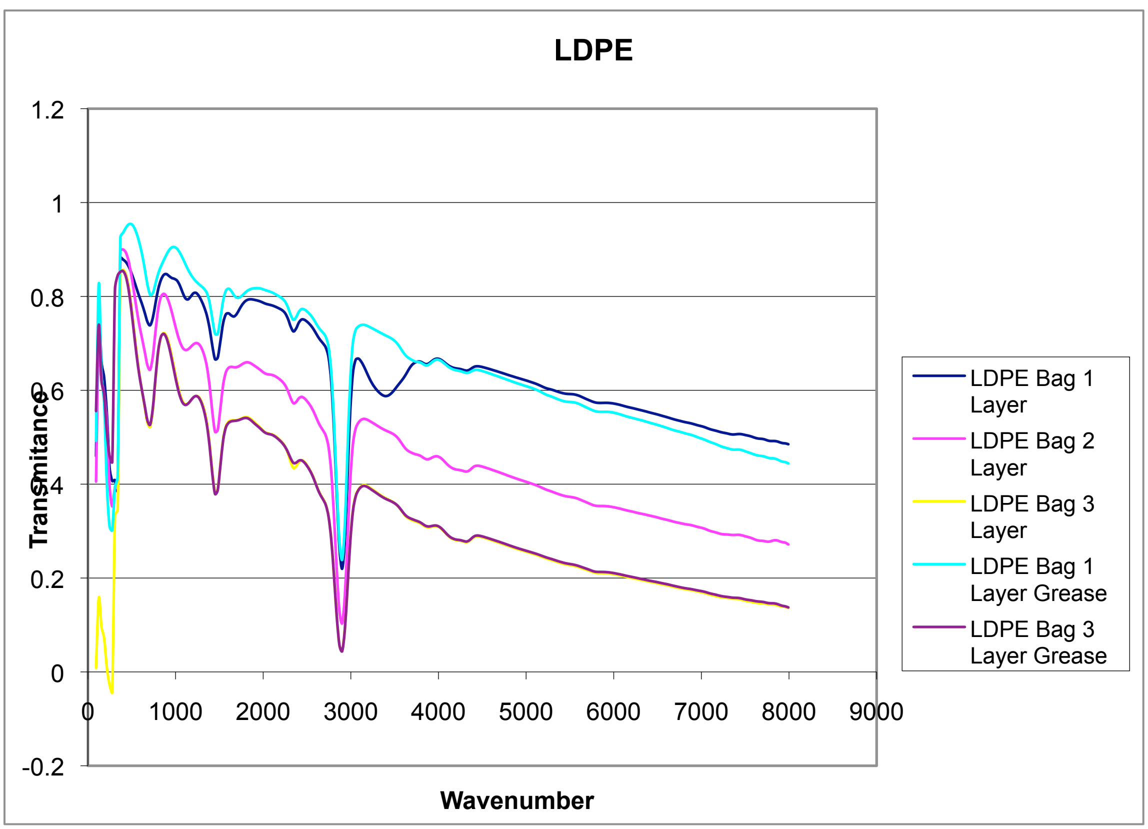
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Wavenumber
Polystyrene Std
Polystyrene Cup 1 Layer
Polystyrene Cup 2 Layer
Polysytrene Cup 3 Layer
Polystyrene Cup 1 Layer Grease
Polysyrene Cup 3 Layer Grease


LDPE
Transmittance
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0.8
0.6
0.4
0.2
0
-0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Wavenumber
LDPE Bag 1 Layer
LDPE Bag 2 Layer
LDPE Bag 3 Layer
LDPE Bag 1 Layer Grease
LDPE Bag 3 Layer Grease

15.0 Archive CD