Chem Factsheet

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Polymers – Biodegradability and Recycling

To succeed in this topic you need to:-
- Be familiar with Factsheet 76 – “Polymers”
- Know basic organic nomenclature
- Be familiar with hydrolysis reactions of esters and amides

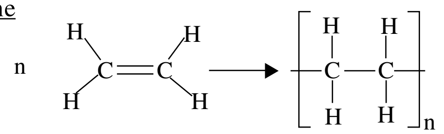
After working through this Factsheet you will:-
- Understand the problems associated with disposing of plastics
- Be aware of the different types of recycling
- Be familiar with the type of plastics that will biodegrade
- Know some example of biodegradable plastics

Introduction
Factsheet 76, Polymers, introduced the key distinctions between addition and condensation polymers but this will be covered again in brief as the distinction is vital as an introduction to the related problems of biodegradability and recycling. The problem boils down to the fact that simple addition polymers are so inert that they take tens, or even hundreds of years, to break down naturally so recycling is the only way to avoid either filling up landfill sites or risking the production of toxic gases by burning the plastic waste.

The production of condensation polymers can, however, lead to plastics that are much more readily broken down by moisture, light or microbial activity in a relatively short period of time.

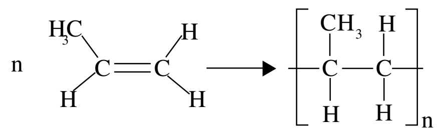
Non-Biodegradable Plastics
Addition polymers are produced from alkenes that are, in turn, obtained from crude oil, which means that their production depends on a non-renewable resource (about 4% of the World’s oil is used to provide the raw materials needed for polymer manufacture and about the same again to provide the energy needed).

Polythene



monomer   repeat unit of polymer

Polypropene



monomer   repeat unit of polymer

The high strength of the carbon-carbon and carbon-hydrogen bonds means that such polymers are very useful, as they are inert. The benefits include:

- Extreme versatility and ability to be tailored to meet very specific technical needs.
- Lighter weight than competing materials, reducing fuel consumption during transportation.
- Extreme durability.
- Resistance to chemicals, water and impact.
- Good safety and hygiene properties for food packaging.
- Excellent thermal and electrical insulation properties.
- Relatively inexpensive to produce.

However, the bond strengths also mean that they are non-biodegradable and will not decompose naturally after disposal. There are three main methods for dealing with the waste: (1) burial in a landfill site, (2) incineration and (3) sorting and recycling.

Landfill


Currently up to 80% of polymers are disposed of by this method and nearly 70% of the waste disposed of in this way is non-biodegradable. The negative issues associated with this method of disposal include:
- Nuisance to local people from gulls attracted to the site, traffic, smells
- Fuel costs for transport of waste to sites
- Cost of treating and sorting before disposal

Incineration


This involves burning the waste at high temperatures in a furnace. The heat energy generated can be used to generate electricity. Although this reduces the need for landfill, the combustion process produces greenhouse gases and the need to remove any toxic gases (e.g. chlorine and nitrogen compounds) from the waste gases produced adds to the overall cost of the process.

Recycling
This can involve simply re-using, mechanical recycling or feedstock recycling.

Reusing is preferable to recycling as it uses less energy and fewer resources. However, even if re-used, plastics have a limited lifespan and will eventually need disposing of.

Whichever process is chosen, the first stage, that goes hand-in-hand with recycling (*and must be mentioned in any exam answer to meet the needs of the mark scheme*) is **sorting** so that different types and colours are separated. Traditionally this is done by hand (making it slow and costly) but increasingly flotation is being used to separate the plastics on the basis of differing densities.

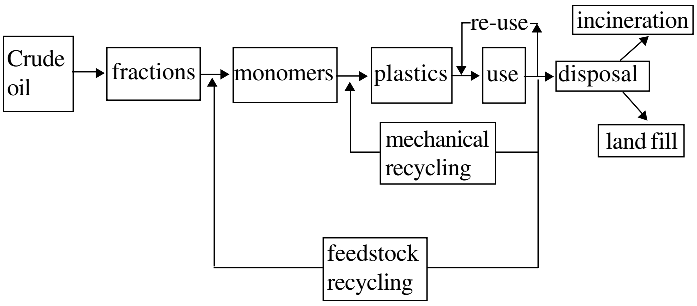
Mechanical recycling involves the melting, shredding and granulation of waste plastics. Following sorting, the plastic is either melted down directly and moulded into a new shape, or melted down after being shredded into flakes and then processed into granules.

Typical plastics shredder

Feedstock recycling describes a range of techniques, which break down polymers into their constituent monomers, which in turn can be used again in refineries, or petrochemical and chemical production. A range of feedstock recycling technologies is currently being explored. These include: pyrolysis hydrogenation, gasification and thermal cracking.

Plastics pyrolysis plant

A typical 'life-cycle' of a plastic can be summarised as below:



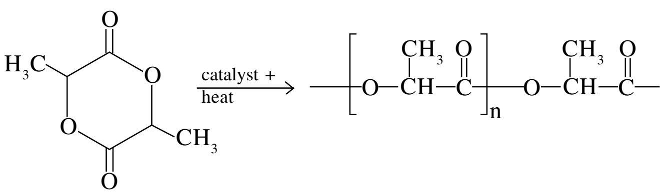
Biodegradable Plastics

Such plastics fall into two broad categories. Some are still based on petrochemicals but include additives that make them degradable whilst others are produced from natural, plant-based materials, such as corn starch, and have the benefit of being virtually carbon-neutral as any carbon dioxide released during their decomposition is matched by that taken in by the plants, from which the plastics are made, during their growth

One type of degradable plastic involves the addition of a metal salt during the manufacture of polythene or polypropene, at levels of only between 1% and 3%. The commonly used transition metal compounds are manganese, iron, cobalt and nickel. None of these are "heavy metals" and none have been shown to be eco-toxic. The salt acts as a catalyst for the breakdown of carbon-carbon bonds. The manufacturing process can be controlled such that the plastic starts to decompose between about 60 days and 5-6 years after manufacture so that it can be adapted to a variety of different uses. A claimed advantage of this process is that the decomposition does not require a biologically active environment and the plastic will become brittle and break down into small flakes wherever it is. Eventually, when the molecular mass of the polymer falls below about 40000, the chains become susceptible to breakdown by micro-organisms.

Poly(lactic acid) (PLA)

Lactic acid can be produced from corn starch or cane sugar and is used to produce the cyclic lactide monomer, for this plastic.



lactide polylactide

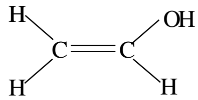
PLA has become a significant commercial bioplastic. Its clarity makes it useful for packaging, such as bottles, yogurt cups, and candy wrappers. It has also been used for waste bags, coatings for paper and cardboard, and fibres for clothing, carpets, sheets and towels, and wall coverings. In biomedical applications, it is used for sutures, prosthetic materials, and materials for drug delivery.

The biodegradability of the plastic is due to the relative ease of hydrolysis of the ester links.

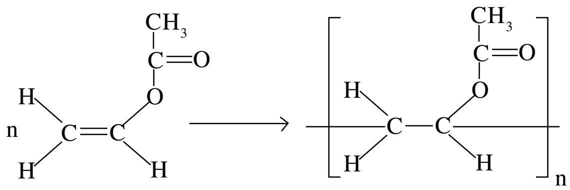
Poly(ethenol)

Poly(ethenol) is also called polyvinyl alcohol or PVOH. It is sometimes called PVA but this also stands for poly(vinyl acetate) so it is best to use PVOH.

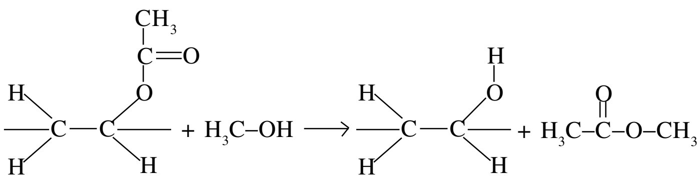
It has the repeat unit shown below. It would be expected to be formed from the monomer ethenol.



However, ethenol is highly unstable. Instead the monomer used is ethenyl ethanoate



The poly (ethenyl ethanoate) is then reacted with methanol to remove the ester groups.



Poly(ethenol) can be used to make plastic bags which dissolve in water. Amongst many other applications, these are used for hospital laundry where the bag can be safely handled to avoid contact with the contents which may be infected. The bag dissolves in the water and the laundry gets washed!

Practice Questions

The questions that are set on this area of the syllabus tend to be fairly predictable and depend on: working out polymer structures from given monomers; working out monomer structures from given polymers; and remembering examples of 'pros and cons' of the various disposal methods.

1. Alkenes such as ethene will take part in reactions to form polymers such as poly(ethene)

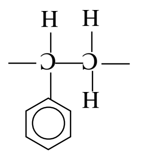
   (a) Draw a repeating unit of the polymer that would be made by a similar reaction from phenylethene, $C_6H_5CH=CH_2$. (2)
   (b) Outline the difficulties involved in the disposal of polymers such as poly(phenylethene) by combustion & by landfill. (2)
   (c) State a property of poly(phenylethene) and suggest why this makes it particularly useful (2)

2. The scientists Ziegler and Natta were awarded a Nobel Prize for Chemistry in 1963 for their work on polymerisation. Part of that work involved the production of poly(propene).
   (a) What type of polymerisation forms poly(propene)? (1)
   (b) Draw a section of poly(propene) to show **two** repeat units. (1)
   (c) State **two** difficulties in the disposal of poly(propene) (2)

3. Hydrocarbon polymers such as poly(propene) can be disposed of by using landfill sites or by burning in an incinerator.
   (a) State one disadvantage of disposal of poly(propene) in a landfill site (1)
   (b) State **one** possible advantage and **one** disadvantage of disposal by burning (2)

Answers

1. (a) *The key points here are: the two carbon backbone; NO double bond; and 'evidence of a continuing structure' i.e. 'terminal bonds' shown as lines extending from each end of the repeat unit.*



The ring could also simply be shown as $–C_6H_5$ as in the question.

(b) *Candidates often overlook the fact that the apparently innocuous-looking word 'and' is a significant part of such questions as it effectively means that this is two questions in one. Candidates who spot this sort of clue will find it much easier to answer the questions in line with the mark scheme. In this case one clear idea is needed that relates to the problems associated with combustion and another clear idea associated with the landfill issue.*

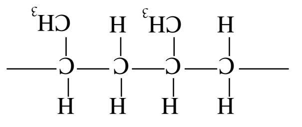
e.g.: Combustion produces carbon dioxide which contributes to global warming
Disposal in landfill is very unsightly,
Disposal in landfill uses up large areas of land, or
Very slow decomposition in landfill sites may produce flammable gases.

(c) *Again note the use of 'and' which makes it clear that there are again two parts to the question which must both be addressed to earn both marks.*

Poly(phenylethene) has a low softening point / is a thermoplastic and so it can easily be moulded into new shapes.

2. (a) *A simple one-word answer is all that's needed here for the one mark available and the clue is in the fact that the name reveals that the monomer is an alkene:* Addition

(b) *It is quite common for an exam question to ask for two (or even three) repeat units instead of simply asking for the repeat unit so be on the lookout for this – it will normally be emphasised in bold: so, in this case, a backbone of four carbon atoms is needed and again there must be 'evidence of a continuing structure'.*



(c) *The key word here is 'disposal' i.e. this isn't a question about recycling. The issues that will need mentioning in the answer will therefore need to relate to combustion and landfill: e.g. Poly(propene) is non-biodegradable:*
Toxic fumes/greenhouse gases will be released if burned

3. (a) 'Non biodegradable' is the 'stock' answer here

(b) *Asking for an **advantage** of a disposal method is a slightly different approach than most questions but again there is a stock answer to fall back on.*

An advantage of disposal by burning is that the reaction is exothermic so the energy released can be used

A disadvantage is the production of toxic fumes/greenhouse gases

Acknowledgements: This Factsheet was researched and written by TonyTooth.
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