Improving the Natural Environment

SCIENCE AND TECHNOLOGY IN ACTION

Sewage treatment

For many years a large proportion of urban waste water was discharged untreated to our rivers, lakes and coastal waters. However, since the introduction of the Urban Waste Water Regulations in 1994, the level of waste water treatment has improved and water pollution from urban waste water sources has been reduced. *Sewage* is the term used to describe wastewater which is produced by domestic, industrial and commercial sources and discharged into sewers. Run-off rain water from roads and paved areas is also collected in the sewerage system, although this has been separated out in recent drainage schemes thus reducing the amount of water which has to be treated at the sewage plant.

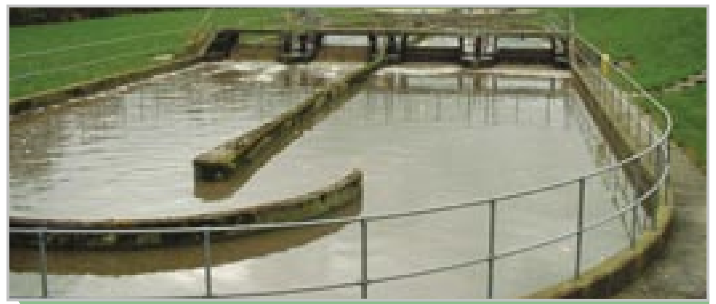

Fig.1 Sewage plant in Carnew Sewage Treatment Plant in Co. Wicklow.

What are the components of sewage?

Sewage consists of *organic waste* and *inorganic waste.* Organic waste includes domestic sewage (human wastes, paper, and vegetable matter, proteins and surfactants, carbohydrates) and industrial/commercial wastes (fats, oils and grease). Inorganic waste includes *nitrates* and *phosphates* from domestic waste and *heavy metals* from industrial waste waters. Sewage may also contain gases, namely *methane (which is explosive)* and *hydrogen sulfide (significant source of odour).*

How is sewage treated?

Sewage goes through several stages of treatment in modern treatment plants. If it were simply discharged untreated into a river or lake, the *micro-organisms* that are naturally present in the water would break down the organic waste into *carbon dioxide* and *water.* This process would use up the dissolved oxygen in the water, depleting oxygen levels which may lead to a fish kill. When all the dissolved oxygen is used up *anaerobic bacteria* (which do not use dissolved oxygen) take over and break down the waste, resulting in the release of unpleasant gases such as hydrogen sulphide.

In a typical treatment plant the waste water is treated using a series of physical, chemical and biological processes. These are *preliminary* or *pre-treatment*, *primary treatment*, *secondary treatment* and *tertiary treatment* and are used are required.

Preliminary treatment

The incoming sewage is pushed through mechanically raked screens to *macerate* the sewage and remove large solids, oily scums and floating debris. The *effluent* is then passed through long concrete grit channels to remove sand or gravel particles. Here the effluent flows slowly and the dense solids are allowed to settle before being removed.

Primary treatment (physical process)

The pre-treated sewage flows into primary settling tanks. The sewage enters at the centre of the tank and rises. The solids settle to the bottom and form a *sludge*. The *settling tanks* have a skimmer mechanism at the top to remove floating particles and a scraper on the floor of the tank to gather the sludge. The clear liquid at the top of the settling tank is transferred to the secondary treatment system.

Secondary treatment (biological process)

This process involves the bacterial breakdown of the nutrients in the effluent. Secondary treatment systems can be broadly categorised as *suspended growth* such as *activated sludge*, or *attached growth* such *trickling filters*, or a combination of the two processes.

In attached growth systems, the waste is *aerobically oxidised* by micro-organisms as the effluent trickles down through a *percolating filter,* which is usually a large concrete tank loosely packed with stones. The stones act as a support for the micro-organisms which grow on the surfaces as a slime, and the loose packing allows a good circulation of air.

The waste may also be broken down aerobically in an *activated sludge unit.* This consists of an *aeration tank* and a *settling tank*. The effluent is fed into an aerated tank that is kept oxygenated by large mechanical agitators which feed air/oxygen needed to support the growth of micro-organisms. Suspended micro-organisms (called *activated sludge*) decompose the organic matter. The sludge may have a retention time of 5 to 6 days in this unit and the dissolved oxygen level is not allowed to fall below 2 p.p.m. in order to prevent anaerobic digestion. The liquid from the aeration tank flows into a settling tank where the sludge settles. Some of the sludge is recycled back to the aeration tank.

Tertiary treatment (chemical process)

This involves the removal of *phosphates* and *nitrates* from the effluent resulting from secondary treatment. *Phosphates* come from washing powders and washing-up liquids. *Nitrates* come from organic materials in sewage and agricultural sources.

How are the nitrates and phosphates removed?

Phosphates are removed by precipitation reactions. They are treated with *lime*, $Ca(OH)_2$, *aluminium sulphate*, $Al_2(SO_4)_3$ or *iron(III) sulphate*, $Fe_2(SO_4)_3$.
In each case an insoluble salt is produced which can be filtered off.

$$PO_4^{3-} + Al_2(SO_4)_3 \rightarrow AlPO_4$$

Phosphate | Aluminium Sulphate | Aluminium Phosphate

Fig.2 Removal of phosphates

$$2NO_3 \rightarrow N_2 + 3O_2$$

Fig.3 Reduction of nitrate ions to nitrogen gas

There are several methods of removing *nitrates*, mainly using denitrifying bacteria. Here the effluent that contains nitrates is placed in a tank which has no free oxygen but contains *denitrifying* bacteria. The bacteria reduce the nitrate ions to nitrogen gas.

Another method is the using of ion exchange. This process is expensive but all nitrate ions are removed from the effluent.

The European Union (Surface Water Regulations 1989) has set maximum limits for various chemicals in surface water:

High levels of nitrogen and phosphorus are harmful to the environment as they act as nutrients which give rise to algal bloom, leading to eutrophication. Eutrophication is the enrichment of water with nutrients, especially nitrates and phosphates, which leads to excessive growth of algae and subsequently the deoxygenation of water.

Chemical	Max limit / p.p.m
Phosphates	0.5 - 0.7
Nitrates (NO_3)	50
Lead	0.05
Chromium	0.05
Cadmium	0.005
Mercury	0.001
Pesticides (total)	0.0005

Fig 4: Table showing acceptable limits of chemicals

What is Biochemical Oxygen Demand? (BOD)

Dissolved oxygen in rivers, lakes and sea water is necessary to sustain sea and other forms of life. The amount of dissolved oxygen used up due to biological action is known as the *Biochemical Oxygen Demand (BOD). Organic pollution* is a term used to describe the oxygen depleting effects caused by the breakdown of organic matter. Biochemical Oxygen Demand is a measure of this organic pollution. As described above, it is caused by organic waste, such as domestic waste, animal slurry, silage and other farm waste materials and industrial waste which are expelled into our waters. When this happens bacteria and other micro-organisms, which are present naturally, are supplied with plenty of nutrients. The nutrients help the organisms to grow and multiply. As these organisms are breaking down the waste into compounds such as carbon dioxide, they are simultaneously using up oxygen supplies.

$$\text{Organic matter} + O_2 \rightarrow CO_2 + H_20$$

Fig.5 Reaction of micro-organisms breaking down waste

If there is too much organic waste present, it may reduce the amount of dissolved oxygen available so much that it may cause the death of fish or the reduction fish numbers.
A sewage treatment plant must reduce the Biochemical Oxygen Demand of the sewage before it is discharged into the river or lake.

The setting of national standards for water, sewage discharges and other effluents by the Minister for the Environment is provided for under the Local Government (Water Pollution) Act, 1977 and the Environmental Protection Agency Act, 1992 and The Urban Waste Water Regulations 2001. Under these guidelines the following limits were set for B.O.D

Calculation of B.O.D.

To calculate the B.O.D. of a sample, two bottles of the water to be tested must be completely filled. This is to ensure no oxygen remains, other than that in the sample. The dissolved oxygen is measured from one of the bottles. The other is stored at 20°C in the dark for 5 days. These conditions are necessary to ensure no photosynthesis occurs, producing oxygen and that constant temperature conditions are maintained. After 5 days the second bottle is tested for levels of dissolved oxygen. The B.O.D. is the difference in these two values.

B.O.D (mg/L)	Example
1-2	Clean Water
20-40	Treated sewage
100	Polluted water
300-350	Raw Sewage
500	Brewery effluent
30,000	Pig Slurry
54,000	Silage effluent

Fig.6 B.O.D Standards for Water

The Environmental Protection Agency (EPA) is an independent public body established under the Environmental Protection Agency Act, 1992. The EPA regulates and polices activities that might otherwise cause pollution. It ensures there is solid information on environmental trends so that necessary actions are taken. The EPA's priorities are protecting the Irish environment and ensuring that development is sustainable. It employs over 260 people who work in ten locations throughout the country.

The other main instruments from which it derives its mandate are the **Waste Management Act, 1996**, and the **Protection of the Environment Act, 2003.** The EPA has a wide range of functions to protect the environment. Its primary activities include:

- Environmental licensing
- Enforcement of environmental law
- Environmental planning and guidance
- Monitoring and reporting on the environmental status- air, water, waste, noise, land and soil
- Environmental research

The EPA's function is to protect and improve the natural environment for present and future generations, taking into account the environmental, social and economic principles of sustainable development.

Find out more on the work of the Environmental Protection Agency on **www.epa.ie** or on **www.sciencetechnolgyaction.com**

Fig.7 Sewage plant in Carnew Sewage Treatment Plant in Co. Wicklow.

epa Environmental Protection Agency

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Syllabus Reference

Leaving Certificate Chemistry:
Unit 9 Environmental Chemistry, 9.3 Water Treatment

Junior Certificate Science:
Section 23B Hardness and Treatment of Water

Learning Objectives

On completing this section, the student will be able to:

- Define sewage and its composition
- Outline the stages of the sewage treatment process
- Define eutrophication and outline its causes
- Define Biochemical Oxygen Demand (B.O.D)
- Calculate the B.O.D. of a sample

General Learning Points

- Sewage is the term used to describe the waste and wastewater produced by domestic and commercial sources.
- Sewage comprises of organic waste, inorganic waste and gases.
- Sewage treatment processes include preliminary, primary, secondary and tertiary stages.
- The preliminary stage is the physical stage and involves the removal of large pieces of debris.
- The primary stage is a physical stage and involve the removal of settled solids.
- The secondary stage is a biological stage and involves the bacterial breakdown of nutrients.
- The tertiary stage of the process is a chemical stage and involves the removal of phosphates and nitrates.
- Eutrophication is the enrichment of water with nutrients, especially nitrates and phosphates, which leads to excessive growth of algae and subsequently the deoxygenation of water.
- Dissolved oxygen in rivers, lakes and sea water is necessary to sustain sea and other forms of life.
- The Biochemical Oxygen Demand of a water supply is defined as the amount of dissolved oxygen in p.p.m used in a sample that has been kept at 20°C in the dark for five days, due to biological action.

Activities

Mandatory Experiments

- To measure the amount of dissolved oxygen in a sample of water by means of a redox titration.
- To determine the total dissolved solids (in p.p.m) of a sample of water by filtration, the total dissolved solids (in p.p.m) of a sample of water by evaporation and the pH of a sample of water.

Examination Questions

2005 Higher Level

In an experiment to measure the concentration of dissolved oxygen in a river water sample, a bottle of water was filled from the river and it was analysed immediately. The experiment was carried out as follows:

A few cm³ each of concentrated manganese (II) sulphate ($MnSO_4$) solution and alkaline potassium iodide (KOH/KI) solution were added to the water in the bottle. The stopper was carefully replaced on the bottle and the bottle was shaken to ensure mixing of the reagents with the water. A brownish precipitate was produced. The stopper was removed from the bottle and a few cm³ of concentrated sulphuric acid (H_2SO_4) were added carefully down the inside of the neck of the bottle using a dropper. The precipitate dissolved and a golden brown solution was produced. The concentration of iodine (I_2) in this solution was found by titrating it in 50cm³ portions against a standard (0.01M) sodium thiosulphate ($Na_2S_2O_3$) solution

(a) Why was it necessary to analyse the sample of the river immediately?

(b) In making the additions to the sample, why should the solutions be concentrated? (6)

(c) Describe how the additions of the concentrated solution of manganese (II) sulphate ($MnSO_4$) and alkaline potassium iodide (KOH/KI) to the bottle of river water should be carried out. What essential precaution should be taken when replacing the stopper of the bottle after these additions are made? (9)

(d) Describe clearly the procedure for using a pipette to measure exactly 50cm³ portions of the iodine (I_2) solution in the titration flask? (9)

(e) What indicator is used in this titration? State when the indicator should be added to the titration flask and describe the colour change observed at the end point (9)

(f) The titration reaction is described by the following equation.

$$2\,S_2O_3^{2-} + I_2 \longrightarrow 2I^- + S_4O_6^{2-}$$

Calculate the concentration of the iodine solution in moles per litre given that 6.0 cm³ of the 0.01M sodium thiosulphate ($Na_2S_2O_3$) solution were required in the titration for complete reaction with 50cm³ portions of the iodine solution(6)

(g) For every 1 mole of oxygen gas (O_2) in the water samples 2 moles of iodine (I_2) are liberated in this experiment. Hence calculate the concentration of dissolved oxygen in the water sample in p.p.m(6)

2003 Q4 Higher Level

(e) What happens during secondary sewage treatment?

2005 Q8 Higher Level

(d) What is meant by the Biological Oxygen Demand (BOD) of a water sample (6)

(e) Describe clearly the process involved in the primary and secondary stages of urban sewage treatment. What substances are removed by tertiary treatment of sewage? (18)

For further examples of past paper exam questions check out www.sciencetechnologyaction.com

True or False

Indicate whether the following are true (T) or false (F) by drawing a circle around T or F.

a) Sewage is composed of organic waste, inorganic waste and gases	T	F
(b) The treatment of sewage is a one stage process	T	F
(c) When nutrients are taken out of the water, this is called eutrophication	T	F
(d) Dissolved oxygen in rivers, lakes and sea water is necessary to sustain organic life	T	F
(e) A percolating filter is a component in a sewage treatment plant	T	F
(f) Eutrophication is the enrichment of water with nutrients, which is beneficial to marine life	T	F
(g) When organic matter reacts with oxygen, carbon monoxide and water are produced	T	F
(h) Denitrifying bacteria. The bacteria reduce the nitrate ions to nitrogen gas.	T	F
(i) There are no laws governing the amount of lead and mercury in water	T	F
(j) Excessive algae can lead to deoxygenation of water	T	F

Check your answers to these questions on www.sciencetechnologyaction.com

Did You Know

The EPA has a resource pack 'The State We're In' which includes videos and worksheets. It is aimed at second level students studying Science or Geography.

Thanks to the new sewage plant in Ringsend, Dublin, the level of wastewater receiving secondary treatment has increased from 20% in 2000/2001 to over 60% in 2002/2003.

The Urban Waste Discharges in Ireland report 2002/2003 for urbanised areas with a population greater than 500 showed that

- 12% of waste did not receive any treatment
- 14% of waster received only preliminary treatment
- 3% of waste received only primary treatment.
- 62% of waste received only secondary treatment
- 9% of waste received nutrient reduction in addition to secondary treatment.

The first signs of plumbing date back as far as 8000B.C. in Scotland, where evidence of indoor plumbing pipes or troughs carrying waste to a nearby creak have been found.

Wastes used to be thrown onto the streets from doors and over-head windows. It is thought the practice of men walking on the outside of a lady while walking down the street originated to prevent ladies being in the line of fire of such waste throwing.

In Ancient Greek times, the water in towns was not safe to drink therefore big fountains were built with water being pumped from less polluted sources.

In the mid 1800's Boston, USA was the location for the first devised system to carry waste from larger cities to nearby water. Early pipes were made of clay, brick and hollow logs.

Biographical Notes

Lajos Winkler

In 1888 Lajos Winkler worked out the Winkler method of iodometric determination of dissolved oxygen in water. The process is so called because it uses iodine. During the writing of his doctoral dissertation, he solved a very important practical problem with his invention of a process which made it possible to determine the amount of oxygen dissolved in water in high pressure boilers. He also devised a simple and intelligent means of implementing his method.

Read about these and other famous scientists at www.sciencetechnolgyaction.com

Revise the Terms

Can you recall the meaning of these terms? Reviewing the terminology is a powerful aid for recall and retention.

Sewage; organic waste; inorganic waste; nitrates; hydrogen sulfide; methane; micro-organisms; carbon dioxide; anaerobic bacteria; B.O.D. (Biochemical Oxygen Demand); effluent; preliminary treatment; primary treatment; secondary treatment; macerate; sludge; settling tanks; denitrifying; aerobically oxidized; percolating filter; activated sludge unit; phosphates; algal bloom; eutrophication; algae; organic pollution.

Check the Glossary of Terms for this lesson at www.sciencetechnologyaction.com