# The evolution of activated sludge

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**The history of modern sanitation and wastewater treatment was spurred by the rapid industrialisation and urbanisation of mid-19th Century England. Greater use of water and centralised distribution, particularly after the flushing toilet was invented, led to inevitable system capacity problems, clogging and overflows. This resulted in the contamination of potable water resources and problems with diseases and odour, including the famous 'Great Stink' of 1858.**

The solution chosen was new sewers, but these created a new problem: dramatic river pollution. Attempts to improve the situation led to developments in wastewater treatment processes, including efforts by Sir Edward Frankland, influenced by Pasteur's bacteriological studies, to better understand the nature of the soil-based wastewater treatment process (sewage farms).

Progress in understanding basic principles was followed by developments in engineering approaches to biological treatment processes, including a move to so-called contact beds with mineral media (William Joseph Dibdin, 1903), and later to percolated (trickling) filters.

Legislation including the 1876 Rivers Pollution Prevention Act could not halt or prevent further river pollution without proper technical measures. The Royal Commission on Sewage Disposal, formed in 1898, coordinated activities that led to a better understanding of the factors affecting the quality of receiving waters, and evaluation of new treatment procedures. That body also formulated standards for biological oxygen demand, suspended solids and full nitrification that were global exemplars for many years.

## The invention of the activated sludge process

The effort to improve treatment techniques ultimately led to the invention of the activated sludge (AS) process in 1914.

Probably the most important factor in this was the work of Dr Gilbert Fowler of Manchester University, who visited the Lawrence Experimental Station in Massachusetts in 1912. This unique facility was used for experimental verification of different wastewater treatment procedures, including aeration in various arrangements.

The work was taken forward in the UK by Edward Ardern, the chemist at Manchester's Davyhulme wastewater treatment plant, and his co-worker William Lockett. The pair realised for the first time the active role of the suspension formed during aeration, now known as AS.

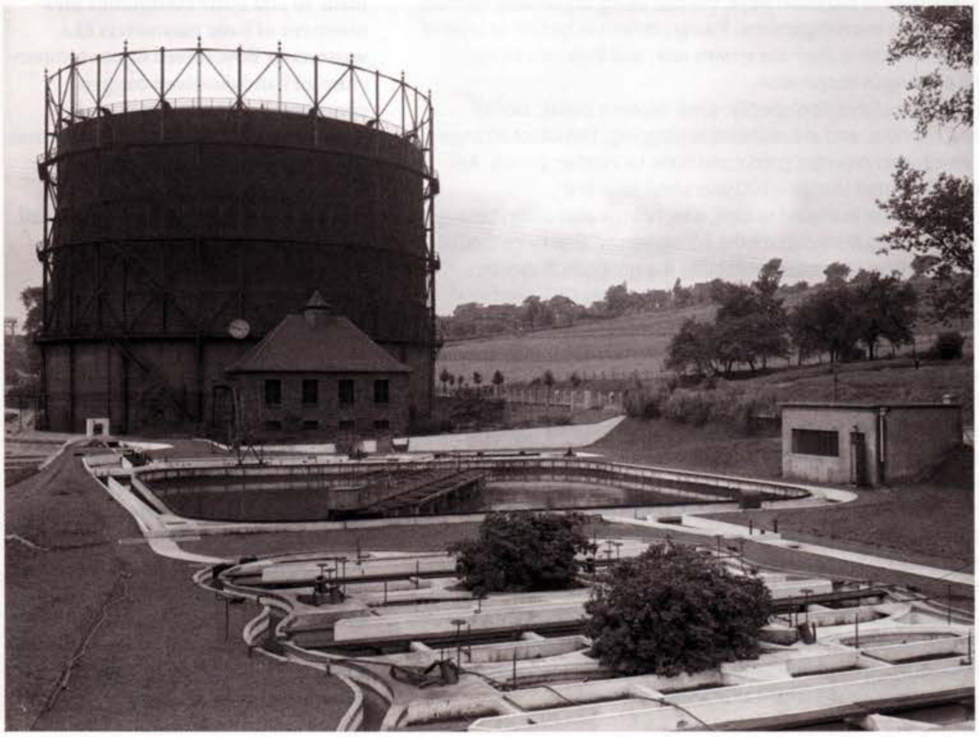
The duo carried out lab-scale experiments at Davyhulme in 1913 and 1914, using glass bottles as the first reactors – lab-scale aeration basins, covered with brown paper to protect them from daylight and prevent algal growth. A new procedure was tried – the sediment was left in the bottle after the effluent was decanted, and a new dose of wastewater added. Lockett and Ardern soon found the amount of sediment increased as the number of batches rose.

Using this technique, the pair found that the aeration time needed for the removal of degradable organics and complete nitrification (full oxidation) could be shortened from weeks to under 24 hours, which made the process technically feasible. Lockett and Ardern's results were published in a famous series of three papers (see notes).

In 1914, the AS process was tested at a larger scale in a mobile pilot plant at Davyhulme. Although this was mostly made of wood and built on the chassis of a horse-drawn wagon, the installation already had most of the characteristics of today's AS process.

From the beginning, both basic arrangements of the process – continuous flow arrangements with separate clarifiers and AS recycling, and the fill and draw arrangement now known as a sequencing batch reactor – were tested. The Davyhulme models achieved aeration using diffused air, first using coarse bubble diffusers, but these were shortly replaced with fine-bubble ceramic elements.

At the same time as the Manchester experiments in 1914, the sequencing batch reactor (SBR) AS process was being tested in a full-scale plant at



**Site of the first activated sludge plant in mainland Europe: Essen-Rellinghausen, Germany. Credit: Archive Ruhrverband.**

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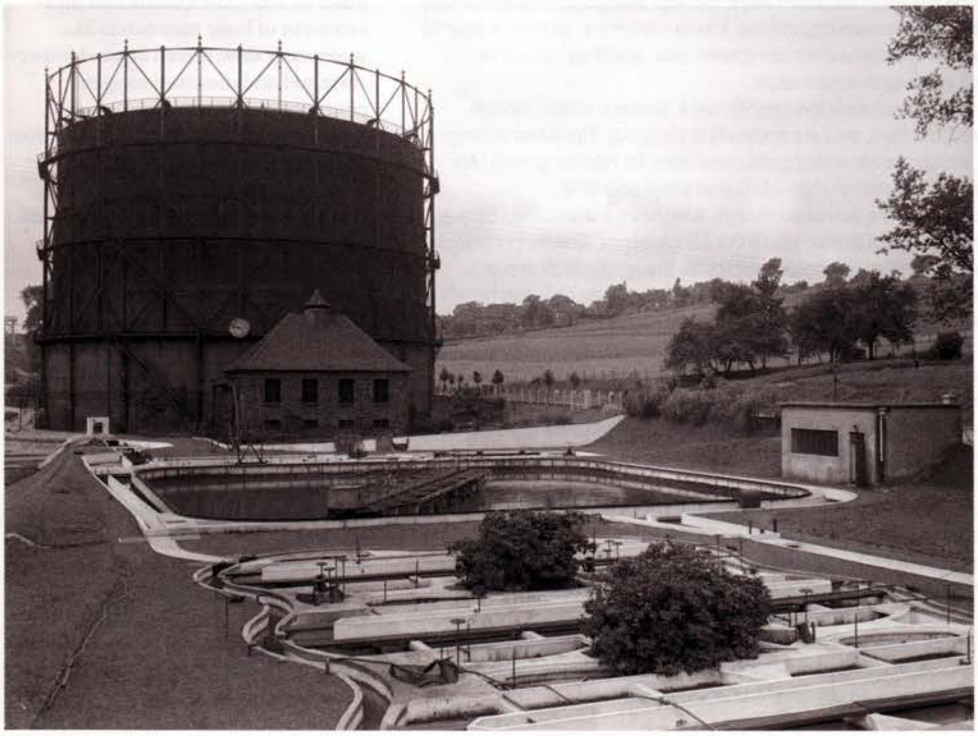


**Site of the first activated sludge plant in mainland Europe: Essen-Rellinghausen, Germany. Credit: Archive Ruhrverband.**

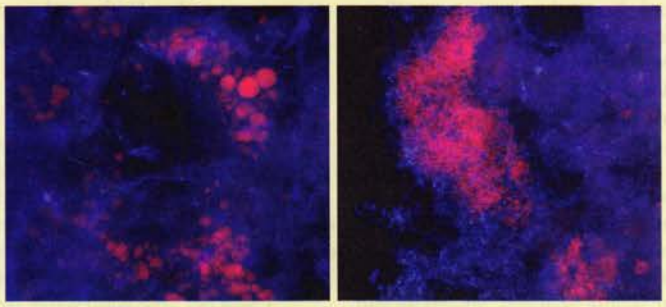
## Modern identification techniques based on molecular biology

In the 1990s Amann, Schleifer and co-workers studied the possibility of using the newly developed method of identification via targeted nucleic acid probes (gene probes) for identifying bacteria important in activated sludge. These techniques, called FISH (fluorescent in-situ hybridisation), were particularly important in identifying difficult microorganisms such as nitrification bacteria and certain filaments.

In 1995 the Körber Foundation awarded the European Prize for Science to a project experimentally verifying the possibility of using gene probes to identify not only organisms in pure cultures but directly in environmental samples such as activated sludge. Later, this technique was improved by microradioautography with radiolabeled substrates, as described by Nielsen (2014).

Molecular biology requires study of a particular organism's DNA in detail. For this it is necessary to obtain a certain amount of DNA. The polymerase chain reaction (PCR) is a biochemical technology in molecular biology used to amplify a single copy or a few copies of a piece of DNA by several orders of magnitude, generating thousands to millions of copies of a particular DNA sequence. Most PCR methods use thermal cycling, that is, alternately heating and cooling the PCR sample through a defined series of temperature steps.

In the first step, the two strands of the DNA double helix are physically separated at a high temperature. In the second step, the temperature is reduced and the two DNA strands become templates for DNA polymerase to selectively amplify the target DNA. The selectivity of PCR results from using primers complementary to the DNA region targeted for amplification under specific thermal cycling conditions. When isolating the nucleic acids from complex consortia of environmental samples (as in activated sludge), some separation techniques are necessary, for instance, DGGE (denaturing gradient gel electrophoresis).



**Fluorescence in situ hybridisation. TOP: FISH micrograph of ammonia oxidising bacteria (320x). BOTTOM: FISH micrograph of polyphosphate accumulating organisms (PAO) (800x). Credit: Lucie Chovancová, Institute of Chemical Technology, Prague**

used was light microscopy. Microscopic examination of AS revealed two principal morphological groups: floc-forming and filamentous microorganisms. Initially, most of the filaments were identified as 'sphaerotilus' but with improved examination techniques (phase contrast, Gram and Neisser staining) more and more morphologically different strains were distinguished. The situation became confusing and a system was necessary.

It is interesting to note that the first manuals introducing filamentous 'morphotypes' were again prepared by engineers (Eikelboom and van Buijsen, 1981, Jenkins et al, 1986). The system greatly progressed understanding of bulking and foaming problems and enabled practical control measures to be shared, because the microscopic analyses performed in different countries could finally be compared. Nevertheless the system soon reached it limits, and more detailed knowledge of the biology and ecology of filamentous microorganisms was needed.

Similar limits for a purely engineering approach were observed in nutrient removal AS systems. These were the response to the steadily growing risk of surface water eutrophication by nitrogen and phosphorus compounds in partially treated effluents from municipal wastewater treatment plants. It was therefore natural that nutrient removal AS systems were intensively studied and applied in full-scale operation in South Africa and then in sensitive areas elsewhere, including the US, Australia and Europe.

Europe's Urban Wastewater Treatment Directive mandated the removal of nitrogen and / or phosphorus in municipal wastewater treatment in sensitive areas, and the rapid uptake of nutrient removal AS systems generated a great deal of practical experience. It was obvious that AS from these systems exhibited some problems that could not be explained without more detailed knowledge of the active microorganisms involved in nutrient removal processes.

Typical issues included a lack of nitrification bacteria activity, biological phosphate removal process instability and competition between these bacteria and other bacteria for the organic substrate. However it is very difficult to isolate and cultivate these microorganisms from AS.

In 1995 Amann and Schleifer from TU Munich published the first reports on the practical application of new identification techniques based on recent development in molecular biology (see box). These techniques, combined with newly formulated principles of AS population dynamics, helped in understanding the practical problems and finding solutions. The application of identification techniques like FISH (fluorescent in situ hybridization) made identifying filamentous microorganisms more accurate and reliable, which contributed to more efficient control of bulking and foaming.

### The AS process as the most significant part of water reclamation

The AS process is now seen as part of a complex approach to municipal wastewater management, reflecting a changed water management paradigm,

## Activated sludge and energy

It is generally accepted that about 50 to 80% of electrical energy consumed at municipal wastewater treatment plants is used in aeration basins (nitrification) and mixing in non-aerated basins (denitrification), so the activated sludge process provides good potential energy savings.

The first avenue is in the production of pressurised air. Fine-bubble diffused aeration is the most common means of supplying oxygen to the AS mixed liquor, and using more efficient blowers is the main way to achieve energy savings. Modern blowers should be able to alter their capacity according to actual oxygen demand.

The second savings route is through aeration basin operation. In conventional activated sludge plants aeration is controlled by dissolved oxygen (DO) concentration. The standard DO set point is 2mg/l, but in nutrient removal activated sludge plants with alternating oxic and anoxic conditions (alternating nitrification and denitrification), significant savings can be made through more sophisticated control of the oxygen supply.

Modern control methods use not only DO measurement but combine the DO value with measuring ammonia and nitrate nitrogen concentrations. The data are then processed using a calibrated mathematical model of a particular activated sludge system (based for example on the IWA model ASM1). This limits air consumption to the necessary oxygen supply (that is, it avoids over-aeration of aeration basins) and also reduces the return flux of DO from the nitrification to pre-denitrification zones of D-N activated sludge systems.

with wastewater no longer seen as a nuisance but a valuable source of water, nutrients and energy. The quality of treated water for reuse is determined in international standards (WHO, IWA guidelines) or through national legal and / or technical standards.

In any case, wastewater treatment for water reuse must consist of biological and chemical treatment, as well as filtration and disinfection, with UV being the most common means of disinfection. When membranes are used for AS separation, filtration and UV disinfection are not necessary.

Reuse of treated municipal wastewater is becoming an increasingly important source of water as a result of modern water shortages. This problem is now acute in 'traditional' dry areas including Namibia, Singapore and parts of Australia and the US, and is being seen in Europe.

Reclaimed water is also used in the UK and other European countries, not only due to the threat of water shortages, but also the steadily growing price of drinking water. The importance of reclaimed wastewater was stressed by the EU Commission's 2012 document, 'A blueprint to safeguard Europe's water resources', in which treated wastewater is described as the most natural alternative source of water for EU countries.

## The future of the AS process

AS is the most widespread treatment technique around the world today, used everywhere people produce wastewater. AS systems are found in treatment facilities on passenger ships, and even in hotels on mountain summits. The AS process is, however, mainly associated with larger wastewater treatment plants.

Demographic forecasts say that in 2020 about two thirds of the world's population will be living in towns. This will stress the role of the AS process as the basic technology used in municipal wastewater treatment plants. At the same time the process is important as the basic operation in wastewater reclamation. The role it plays in municipal and industrial water management means that its future is safe for the next few decades.

## Role of the IWA

The development of the AS process is closely connected with the activities of the IWA (and its predecessor associations IAWPRC / IAWQ). One of the most traditional Specialist Groups, the group on the Design, Operation and Costs of Large Wastewater Treatment Plants, is very much involved in the application of the AS process in wastewater treatment. This group also supported research and development in fields such as AS separation, application of nutrient removal AS systems and design and modelling of the AS process.

A very substantial contribution to AS research was facilitated by the Specialist Group on Activated Sludge Population Dynamics, which was established in 1988 and is now renamed the SG on Microbial Ecology in Water Engineering. The group formulated the basic principles of AS population dynamics in the early 1990s. Later, it provided a forum for exchanging ideas and improving new identification techniques based on achievements in molecular biology.

It was therefore only natural that in 2014, when wastewater professionals celebrated the 100th anniversary of the invention of the AS process, the IWA organised a specialist conference in Essen summarising the current state of development of the process and expected future progress. For this conference the IWA has also published a specialist monograph covering all important aspects of the AS process (see references).

Readers who are interested in recent developments in the AS process and its application to municipal wastewater treatment and reuse can also learn more at the forthcoming IWA specialist conference (see www.lwwtp2015.org). ●

## Activated Sludge - 100 Years and Counting

Editors: David Jenkins and Jiri Wanner


Activated Sludge - 100 Years and Counting covers the current status of all aspects of the activated sludge process and looks forward to its further development in the future. It celebrates 100 years of the activated sludge process, from the time that the early developers presented the seminal works that led to its eventual worldwide adoption.

The book assembles contributions from renowned world leaders in activated sludge research, development, technology and application. The objective of the book is to summarise the knowledge of all aspects of the activated sludge process and to present and discuss anticipated future developments.

The book comprises invited papers delivered at the conference 'Activated Sludge... 100 Years and Counting!' held in Essen, Germany in June 2014.

Activated Sludge - 100 Years and Counting is of interest to researchers, engineers, designers, operations specialists, and governmental agencies from a wide range of disciplines associated with all aspects of the activated sludge process.

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## Notes

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