Sustainable engineering design: an interactive multimedia case study

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Abstract *This paper presents an interactive multimedia case study in waste water management developed at the University of Surrey, UK. The case study considers waste water treatment methods used in a typical sewage treatment works (STW). The works uses a biological treatment process which depends on the provision of dissolved oxygen to the incoming waste water stream. There are several alternative ways of providing oxygen and this case study explores the technical, environmental, economic and social aspects of the various alternatives. The aim of the case study is to suggest which criteria chemical engineers should consider in order to identify more sustainable process alternatives. The case study is developed as an IT-based interactive learning package (CD-ROM).*

Introduction

Engineering has had a significant impact on its environment, from the socio-economic effects of industrial breakthroughs to widespread improvements in community health (Perkins, 2001). In the twenty-first century, engineers continue to use their skills to develop and provide technologies that improve the lives of people everywhere. At the same time, the engineering profession is facing new challenges in their efforts to advance economic and social development, and protect the environment through sustainable development. Engineering professionals and students must contend with the explosion of knowledge which requires both greater specialization and more generalist skills to provide the context for application of that knowledge in industry and the community (Brown, 2001).

Engineering education needs to respond to these new challenges. The evolving engineering agenda requires that learning and training programmes provide future engineers with an understanding of a wide range of

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environmental, technological, economic, and social issues, as well as raise their awareness of how to work and act sustainably (Perdan *et al.*, 2000). The resulting concept is that engineering students need to be educated to become technical experts who act as social agents, rather than just technicians (Clift, 1998).

Most recent developments in engineering education in the UK seem to support this line of thinking. The Sustainable Development Education Panel (SDE Panel, 1999), established by the UK government's Department of the Environment, Transport and Region (DETR), in 1998, stated in its first annual report: "Education for sustainable development enables people to develop knowledge, values and skills to participate in decisions about the way we do things individually and collectively, both locally and globally, that will improve the quality of life now without damaging the planet for the future" (DETR, 1999).

In 1998, the UK-based organisation Forum for the Future conducted an audit of Higher Education (HE) engineering curricula as part of the SDE Panel's HE work programme. The survey was supported by the Royal Academy of Engineering (RAE) and the Institutions of Chemical, Civil, Electrical and Mechanical Engineers. The objective of the curriculum audit was to assess the current status of sustainable development education within higher education engineering schools or departments, and to take engineering educators' views on appropriate sustainable development learning (SDE Panel, 1999). Informed by the findings of the engineering education survey and the comments of educators, the SDE Panel has developed a sustainable development education specification related to engineering education with the objective of developing and implementing sustainable development (SD) education strategies.

The Panel's position paper suggests that, in order to provide the knowledge and skills the future engineer will need, the engineering programmes, modules or learning materials should include an understanding of the interdependence of natural, social and economic systems, the needs and rights of future generations and an appreciation for the need for precaution (SDE Panel, 1999). A necessary grounding in environmental science, combined with sound understanding of technological and social issues should help future engineers in developing and designing new ways of meeting human needs which impact less on the environment. In addition to providing a firm theoretical and practical grounding for evaluating technical, social and economic aspects of environmental problems, and knowledge of the various analytical tools and methods available to help the problem-solving process, the engineering educational programmes should also enable students to understand the role of the engineering community in promoting sustainable development, and help them in developing a sense of social responsibility (Perdan, 2001). The premise for this multidisciplinary approach to engineering education is that the engineers who will "make a difference" in future will need to be first-rate engineers and applied scientists, but will also be required to have a broad understanding of the social and philosophical context in which they will work (Clift, 1998; Azapagic, 2001).

The paper has also suggests that SD education is best integrated into specialist courses through learning activities which are firmly set in the context of the specialism, and that different learning activities and learning materials will be needed to deliver the sustainability learning agenda to students from the different branches of engineering (SDE Panel, 1999).

As a response to the changing engineering agenda, a number of teaching and training programmes have been developed at the University of Surrey, UK. These programmes incorporate the multidisciplinary approach to engineering education and correspond to the sustainability learning agenda set out in the position paper by the SDE Panel. Although strongly grounded in an engineering discipline, the emphasis of these programmes is on sustainable development, the problems that are created by human activities and on the contribution of the engineer to solving them.

The intention is to educate the new type of engineer (Clift, 1998), who will not only be capable of designing and operating facilities to produce products and manage wastes, but who will also be able to go beyond waste management and re-engineer processes to reduce or avoid generation of waste. They will be able to understand the technical, economic and social influences that drive the way in which goods and services are provided, which help or limit recovery and recycling of used products, and which limit the take-up of clean technologies (Azapagic *et al.*, 2000).

As a part of these developments, we are also exploring the ways in which we could use more advanced teaching methods to implement this multidisciplinary approach. Although significant multidisciplinary learning material is already available at the University of Surrey, ongoing work aims to develop, organise and consolidate case studies, findings of completed or ongoing projects, and course notes into an all-inclusive teaching and learning resource. The authors of this paper are involved in a project to develop a comprehensive IT-based learning resource (a multimedia learning package) comprising a set of multidisciplinary case studies and support material, in order to aid engineering students in understanding the concepts and solutions of SD. The IT-based learning resource is being developed to cover the following elements:

- introduction to sustainability concepts; and
- case studies and sustainable solutions.

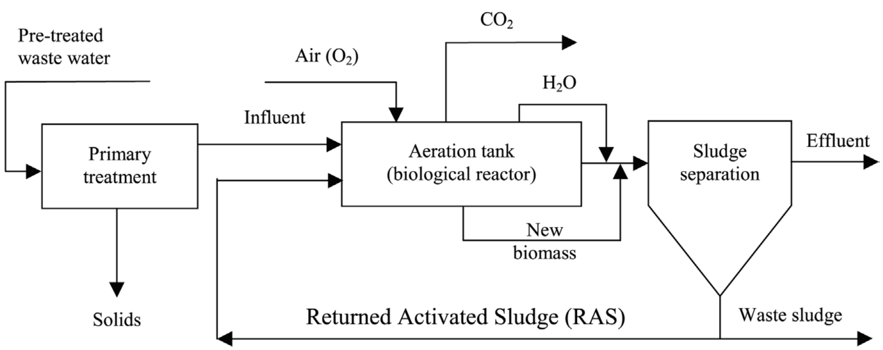
The project is supported from two sources: the University of Surrey's Strategic Fund for Teaching and a grant from the RAE for a Visiting Professor in Engineering Design for Sustainable Development. Following recommendations by the RAE (McQuaid, 2000), the case studies will be real rather than theoretical with emphasis on principles with the appropriate amount of engineering detail. Students will have to examine a range of possible options and will have to evaluate the trade-offs to make “right” decisions. Each case study will have a multidisciplinary approach which will combine engineering, economic, social and ethical elements. Engineering students will also have to learn how to cope with inadequate information and uncertainty requiring construction of scenarios, making assumptions, performing sensitivity analysis and exercising judgement. As an illustration, the rest of this paper presents a case study in waste water management that has been developed as a part of this project.

Case study

The case study, prepared for level 1 Chemical Engineering students, considers waste water treatment methods used in a typical sewage treatment works (STW). The works uses a biological treatment process which depends on the provision of dissolved oxygen to the incoming waste water stream (Winkler, 1981). There are several alternative ways of providing oxygen and this case study explores the technical, environmental, economic and social aspects of the various alternatives. The aim of the case study is to indicate which criteria chemical engineers should consider in order to identify more sustainable process alternatives. The case study has been developed as an IT-based interactive learning package (CD-ROM).

Structure

The case study is organised in several sections. The introductory sections give a background on the supply of fresh water and the sources and measures of water pollution, followed by an overview of the waste water treatment processes used in a typical STW (see Figure 1). Because of the organic nature of contamination of the waste water from domestic and commercial activities, the



Source: Adapted from Kiely (1997)

Figure 1.
Typical layout of activated sludge system

emphasis in the rest of the case study is on biological treatment. In particular, the study concentrates on aerobic processes which use activated sludge (i.e. micro-organisms) to clean up organic pollution.

Students are introduced to the basics of this process and it is explained that the key limiting factor is the provision of a sufficient amount of oxygen dissolved in water in the aeration stage, to ensure complete breakdown of the polluting organic material by the activated sludge. They are presented with several aeration techniques for doing this, including mechanical aeration, coarse bubble aeration and fine bubbles or jet aeration. For each, there is a balance between the effectiveness of the process, its cost, and the associated environmental impacts, and students have to make the appropriate choices to identify the most sustainable solution. The courseware explains each of the methods by using animated figures, illustrated later in the paper.

In addition to the air-based aeration systems, students are also presented with another alternative: the use of oxygen instead of air. Students realise that the use of pure oxygen in the aeration process has an immediate attraction: it would speed up the reaction, because more oxygen would be available per unit mass of pollutant and per unit time. This also suggests that, depending on the details of plant design, a smaller amount of gas, i.e. oxygen, needs to be delivered to the aerobic tank. However, they also need to know that a complete evaluation of the oxygen-based systems has to take account of the economic and environmental costs of obtaining pure oxygen usually by separation from air, and where, how, and in what quantities the separation is done.

It is therefore important that students identify the best air separation process that minimises environmental and economic burdens. They can trade-off these with the process efficiencies and environmental and economic costs of the air-based systems.

For these purposes, the case study examines two basic separation techniques:

(1) *Cryogenic* (separation by cooling): utilising the different boiling points of liquefied gases in the air, and

(2) *Adsorption*: utilising different rates and affinity of adsorption of the components in the air.

Cryogenic separation can yield liquid oxygen, while adsorption methods yield gaseous oxygen. Oxygen can be transported in either form, in pressurised and/or refrigerated road tankers. The choice between the cryogenic (liquid) and gaseous forms depends on a number of factors, including financial and energy costs. Furthermore, there are significant variations in economies of scale between these options: there is a choice between a small scale air separation plant situated on the STW site and a larger scale plant located elsewhere, where the oxygen has to be transported to the STW. Students have to compare these options, together with their environmental and economic costs.

Specific considerations

The case study examines theoretical considerations discussed above in the context of a typical real sewage treatment works. First, it is examined what considerations are important in choosing the appropriate process or technology. After each section a number of questions are posed for students to answer. Finally, the students are asked to identify the "most sustainable" aeration technology for the STW considered in this case study.

The STW in this case study serves a population equivalent to 48,000 people. Waste water is produced at a rate of 200 litres, i.e. 0.2 m^3 or 0.2 tonnes, per head of the population per day. Figure 2 illustrates the influent, in-process and effluent flows through the works.

Students are provided with the following data on the flows in the STW:

- The works operates continuously through the 24 hours of the day, but the flow rates of influent waste water may vary substantially depending on the time of day, the season, and the state of the weather. STWs are typically designed with capacities five times larger than the expected inflow in dry weather (in wet weather, the rain dilutes the waste water and increases the total flowrate). In this case study we assume constant flow rates.
- In the primary treatment stage, 480 tonnes of settled solids and the associated waste water are removed.
- The remaining influent is mixed with 6,720 t/day of returned activated sludge (RAS).
- The combined flow of RAS and the influent water is then split equally between the two reactor lanes.
- On exiting the reactor lanes, the two sludge-water streams are fed into the two secondary settlement tanks. From each of the settlement tanks, a

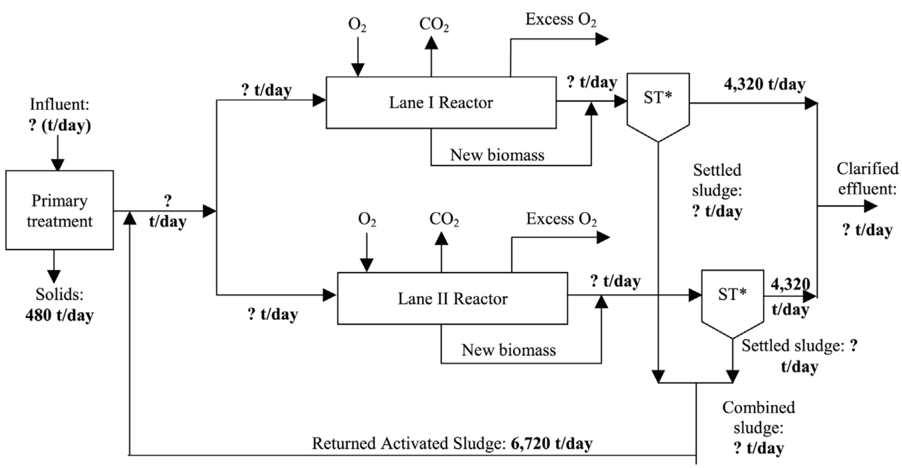


Figure 2.
Flow diagram representing a sewage treatment works serving 48,000 people

stream of 4,320 tonnes per day of purified water is fed back into the environment.

- The balance from each of the secondary settlement tanks is also drawn off and combined into one stream. Of this, 6,720 tonnes per day are returned as RAS for blending with new influent after primary settlement.
- The remainder is the "waste", or "surplus" sludge, which is extracted for final disposal.

Students are then asked to examine different process considerations that will influence the choice of the aeration technology such as oxygen demand, efficiency and energy requirements. They have to perform a simple mass balance by calculating some of the flows in Figure 2, and to calculate the amount of oxygen in kg/day remaining after the biological treatment of water.

After the completion of these tasks, students are then asked to take into account technical, economic and environmental considerations related to both the air- and oxygen-based systems. Technical aspects include oxygen efficiency and power consumption and the energy demand and the associated costs to separate the air and generate the oxygen in the oxygen-based systems. Regarding environmental issues, students are asked, for example, to calculate the following:

- emissions of CO_2 associated with the energy required to produce 1kg of O_2 in the large-scale cryogenic plant and in the small-scale PSA unit and compare the results;
- the contribution to global warming per year, given the oxygen demand in the STW per day and the oxygen utilisation of 95 per cent.

Economic considerations include economies of scale and operating costs of separation units. At this stage, they are asked to decide which process they think is most suitable for air separation, given technical, economic, environmental and social criteria.

The case study continues to examine the main social considerations associated with the aeration technologies considered here, including noise, odour and increased transport (the latter applying for the oxygen-based technology only). However, there are wider social issues to be considered in relation to any STW and they include:

- the service provided by the STW and the benefits it yields;
- the social acceptability of STW and the "NIMBY" syndrome (not-in-my-back-yard);
- planning permission and consultation processes involving the local population;
- land use for the waste water treatment works and possible displacement of local population.

At this point, students are asked to identify the "social" service provided by a sewage treatment works and the benefits of treating the waste water, and to express their views on the people who reject proposals for siting of a sewage treatment (or any other plant) in their neighbourhood (the "NIMBY" syndrome).

The students' final task is to put together all technical, environmental, economic and social aspects that they have examined for different aeration process alternatives and to choose the most sustainable option. In effect, they carry out a multicriteria decision analysis to make a compromise solution – a process often encountered in engineering decision-making. However, the main difference here is that in addition to the more traditional technical and economic criteria, students are also trained to consider wider issues, relevant to sustainable development.

Format

The case study has been developed as an IT-based interactive learning package, containing text, graphics, sound, animations and interactive exercises. To create the learning package we used Authorware – a commercially available multimedia authoring tool, specifically designed for the development of educational and training applications.

Figure 3 and Figure 4 show two examples of the snapshots of animations used in the case study.

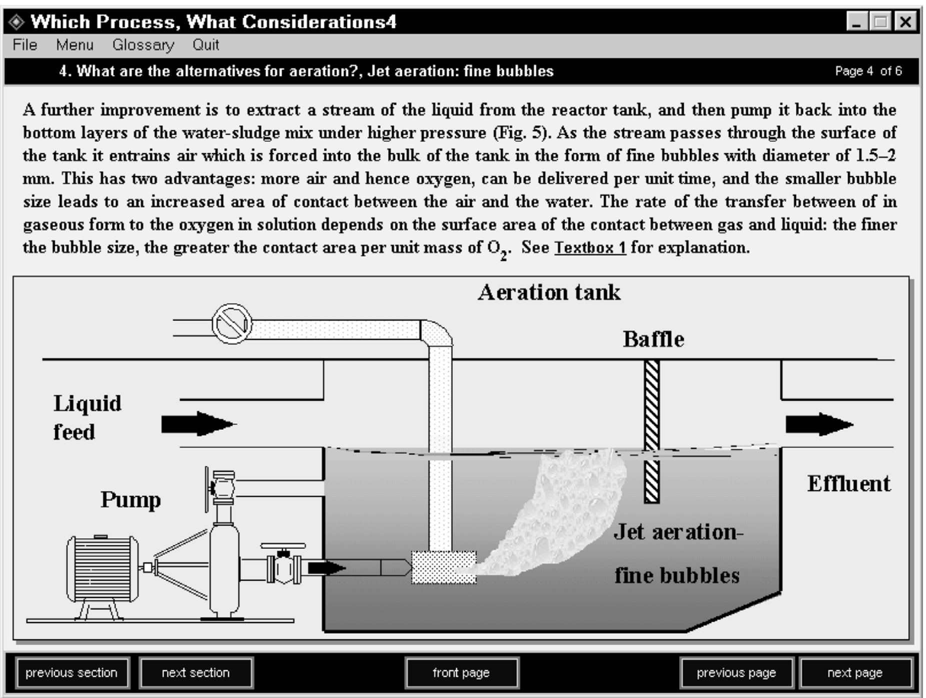


Figure 3.
Animated figure describing Jet Aearation

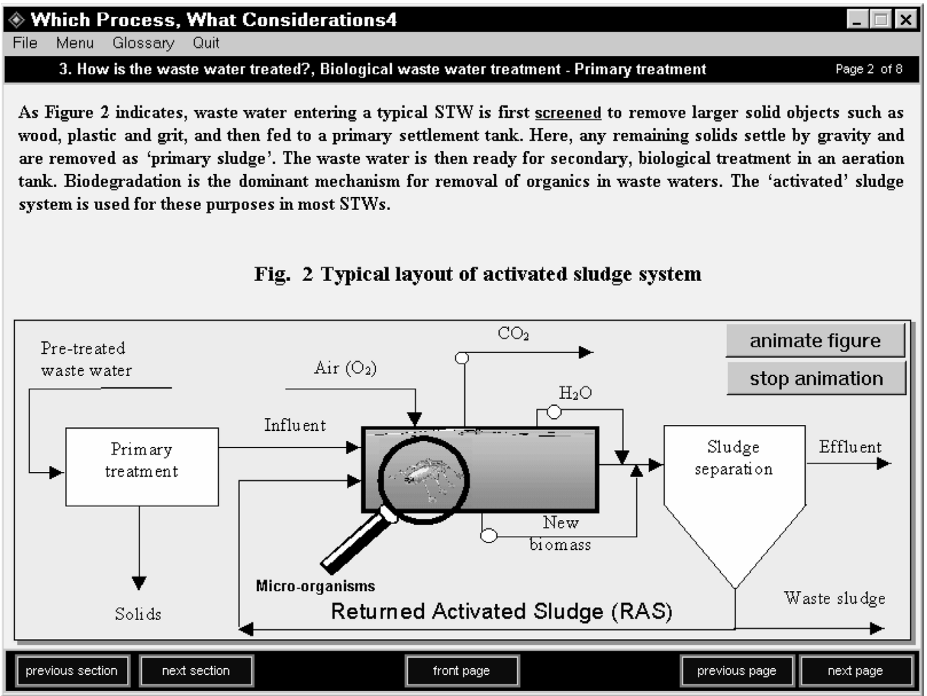


Figure 4.
An example of the case study's animations

The interactive format of the case study with its non-linearity, hypertext and hyper media, enables the student to have more control over how to use the application by making choices about which links to follow. Of course this is only partial control, insofar as he/she is using a hyperspace which has already been defined by the authors of the application, but nevertheless this does represent a qualitative shift of control to the user. For instance, the student can choose to investigate a topic in depth ("vertically") by following the "hyper trial", or to view information "horizontally" by not following links. We believe that this degree of interaction with, and control of, the learning package can increase student motivation by making the student more in control and also by simply being more fun to use than a more conventional learning material.

Another advantage of IT-based learning packages over the text-based variety is that the application looks visually more attractive. If the learning package only includes a few images, at least this gives relief from screens of text and stimulates the eye, even if the images have little pedagogical value. More often than not, however, the inclusion of non-textual media into courseware, for example small animations to depict an engineering function, adds pedagogical value to the application.

The loose, associative and non-sequential structure of multimedia learning packages can also be a disadvantage (Riley, 1995). If the student moves through the material following associative links the danger is that he/she will be unable to place the information learnt within a coherent overall structure and this could result in misunderstanding of the subject in question. An additional danger in the hypermedia approach is that the student could indulge in clicking on links as they appear and going from link to link without any serious attempt to assimilate the information contained in the pages. Moreover, the more non-textual clips in an application, the greater is the likelihood that a student may flick through the application, ignoring any text and playing any clips he/she comes across – the equivalent of browsing through a book looking at the picture.

In the process of developing the interactive case study in waste water management we spent considerable time and effort designing both the structure of the package and its interfaces, in particular its navigation facilities, to avoid these pitfalls. While no one can legislate against the irresponsible and unmotivated user, we hope that, at least, we have managed to minimise the danger by making a coherent structure of the learning package for motivated learners.

Conclusions

The development of this interactive case study compliments our plans to further develop innovative learning techniques, particularly IT-based interactive learning materials, and enhance the engineering learning by applying leading-edge concepts and approaches. The educational strength of IT-based interactive open learning materials is their capability of interaction, data storage and hypermedia facilities. We believe that the translation of the conventional educational material (i.e. the case studies and support material) into an IT-based interactive open learning package, provides a more convenient and efficient access to a large body of interdisciplinary data and audio-visual materials, thereby offering a pedagogical improvement on conventional learning activities and materials. Yet, a distinctive pedagogical quality of this case study, in our opinion, lies not so much in its interactive, open-learning character, but rather in the introduction of problems which have social, environmental and ethical dimensions into engineering learning activities and learning materials. We hope that the case study is a good example of the multidisciplinary approach to engineering education, the approach that is, we firmly believe, needed to respond to a changing engineering agenda.

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