ON-SITE TREATMENT FOR SUSTAINABILITY

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1 Introduction

Technology embodies a serious threat to the wellbeing of this planet. The human threat to Earth started with the mastery of fire which was the key to improved hunting, extension of diet, forging agricultural implements and eventually mining and industrialisation. These abilities and technologies have enabled man to become the dominant species on Earth. This comes at the expense of exploiting natural resources and controlling plant and animal life. Humans' astounding technological prowess, together with an irrepressible procreative urge, has been as dangerous as a gorilla with a machinegun - fast and powerful with little sense of responsibility. To compound the problem, humans congregate in populous colonies, known as cities, where resource demands are concentrated and huge amounts of waste are generated. This problem has become even more pronounced during the last century.

Central processing and disposal of wastes has been man's solution to date to cope with the ever mounting problem of waste generation in the cities. It has become an accepted social approach to flush manes bodily wastes in a dilute form to central processing plants where the water – with varying degrees of success – is separated from the wastes. Apart from insatiable demands for water, this leads to huge quantities of both solid – sludge – and liquid – effluent – streams to be disposed of.

Technology has progressed to the point where most of the waste management problems are under control by more technology. However, affordability and energy requirements for many of the high-tech solutions remain a serious drawback on these solutions. Expensive solutions are not universally acceptable and dependence on non-renewable resources for energy production, with concomitant additional pollution is not a sustainable solution to waste management.

A huge collaborative effort between professions to find solutions to the problems caused by humanity is required. Natural scientists make a substantial contribution as they best understand many of the basic principles at the root of the problems. Engineers and technologists are educated to be problem solvers, skilfully and artistically applying scientific, sociological and economic principles, in this case to ecological challenges. Such solutions should be aimed at sustainability. This paper will demonstrate how environmental protection can be achieved by strategic use and reuse of resources and waste minimisation practices. On-site management, disposal of wastes and reuse is often much more environmentally sensible, simpler and ecologically sustainable than huge central processing approaches.

Sustainability is about maintaining, supporting, enduring and keeping up indefinitely. It is from the Latin root *sustenere*, to hold, and closely related to *sustenance*, from the same root which means food. It has become a cliché, or buzz word to many and its true meaning is sometimes lost. The Institution of Engineers Australia defines sustainability as below.

Sustainability: a characteristic of a process or a state that can be maintained indefinitely

OR

The ability to maintain a high quality of life for all people, both now and in the future, while ensuring the maintenance of the ecological processes on which life depends and the continued availability of the natural resources needed.

Environmental engineering is about ensuring the sustainability of technology, but the concept reeks of an oxymoron, in the style of *military intelligence, rural prosperity, Microsoft Works* ™ and *university administration*. Engineering is all about mechanical devices, construction, site clearing, mining, manufacturing, power generation – which degrade the environment. So how can you have *environmental* engineering?

While there are a number of professions that aim for sustainability, including rural scientists, agriculturists, environmental scientists and natural resource managers, there is also need for technical specialists to help engineer solutions to the enormous problems of supply and disposal of the excess. There is a bit of an environmentalist in all of us and all engineers should be environmentally aware engineers, but there is a need for specialist environmental engineers and technologists. Environmental engineers are educated

- to understand the underlying production methodology and to grasp the applied principles of minimising the impact of by-products and selecting better options for sustainability;
- to operate by taking resources from and introducing products into the environment in a way to minimise impacts and ensure new technologies are sustainable;
- to minimise the impact of human populations, managing their wastes, recover resources and develop renewable sources of food and energy.

Environmental engineers therefore play an important role in the amelioration of the impact of technology. An important tool in this is on-site treatment and recovery. This paper covers areas in which environmental engineers play important roles and some case studies:

- ♦ The global impact of humanity
- ♦ Resource recovery
- ♦ Sustainable energy sources
- ♦ Limiting pollution
- ♦ Preventing the introduction of foreign species
- ♦ Converting waste organics into food
- Pesticide destruction

2 The Global Impact Of Humanity

This beautiful planet of ours is under threat of explosive population growth of one species: *Homo sapiens*. The impact of *H. habilis* and *H. erectus* was probably quite small – about the same as for animals with an equal body mass to ours and estimated populations were 3 to 4 orders of magnitude lower than today.

Control of fire allowed our ancestors to extend their diet, preserve food and forge weapons to become more effective hunters. Ultimately it led to agriculture and mining – control over primary resources. Since the industrial revolution, our ability to mass-produce has caused the impact of human settlements on the rest of the environment to increase exponentially. Rapid technological development during the 20^{th} century, has led to excessive demands on natural resources, notably fresh water.

The most important ability of humans, which distinguishes us from other species, is the ability to think. This has enabled us, relatively weak and frail beings, to plan and largely adapt our environment to suit us and make us the dominant species on this planet. This adaptation poses a threat to the environment, as we have not completely considered the consequences of our actions.

There is little doubt that there are too many humans on this planet – it has reached a staggering 6 billion during 1999. This cannot be avoided and the population size will even touch 10 billion before it will stabilise, extrapolating present trends. All these billions need food, clothing, housing, energy and transport, requiring immense resources. Production to fulfil these needs is resulting in intolerable stresses on the environment – wiping out or decimating other species and setting course for global disasters. The capacity of the earth to sustain human populations has been exceeded, and the human population is having a dangerously negative impact on the natural environment. If you can read this, you are part of the problem.

Evidence of the devastating effect of over-exploitation and pollution is not hard to find. Destruction of the rainforests, global warming, depletion of the ozone layer, Lake Pedder, the Murray-Darling and the largest monument of life - the Great Barrier Reef, are all gradually being degraded or disappearing.

The situation is exacerbated because human populations become increasingly urbanised. Demand for natural resources and waste generated is then even more concentrated. The human population requires waste processing at central facilities, massively increasing the point source pollution and size of disposal areas required. New York City, for example, has a landfill, Fresh Kills, the size of Armidale. A popular alternative is burning, which greatly reduces volumes and produces energy, but significantly adds to air pollution.

A simple example of the effect of urbanisation on waste management is a cannery. When people process their own fruit or vegetables in a rural environment, all the solid waste could be used as garden compost or animal feed and liquid waste used in the garden. When these are processed at a cannery, for the benefit of city dwellers, the solid waste and cleaning water is concentrated and it is much more challenging to dispose of or reuse the wastes. The same applies to almost any food products when comparing small to large scale processing. However, this does not imply that the situation cannot be salvaged, but it requires the development and implementation of some imaginative technology. More on-site processing and disposal of waste could greatly reduce present stresses.

3 Resource Recovery

Most primary resources are from Earth. Technological development depends on these resources and care should be exercised to use biological and mineral resources in such a way as to ensure that there will always be enough for future generations and to minimise the impact on our environment and fellow species on this planet. Burning fossil fuels and wasting metals and nutrients are all examples of unsustainable practices. These substances are either from limited supplies or require high energy inputs upon replacement. Furthermore, discharging these wastes into the environment causes ecological changes and affects the global climate.

The vast human populations are extremely demanding on the environment, particularly towards water resources. Land animals of about human mass manage quite well on about two litres of water per day. The human animal requires on average a hundred times as much; Australians and North Americans even 250 times as much. Humans also deposit their wastes into it, polluting freshwater resources and the oceans. Large quantities of water are used to flush away our wastes, but as always, dilution is not the solution to pollution - it only spreads it wider and further. This pollution is destructive to the environment, as is the need to store large quantities of water by damming up rivers - interfering with the natural flow of water.

The urban human approach to sanitation: dilution of bodily waste with water and subsequent, not totally successful, efforts to purify this waste water in centralised facilities, must appear absurd to an uninvolved observer. Wastewater treatment plants in cities are distant from potential users of both effluents and sludge biomass. Reuse within the city would require excessive further processing and redistribution to a great many users. This technology exists and the author has previously been quite active in the field of water reclamation for potable purposes. This is quite possible but expensive compared with the treatment required for irrigation. The removal of the plant nutrients nitrogen and phosphorus for environmental disposal is difficult and costly to accomplish, and present technology limits the removal to about 90% only, which is insufficient to prevent eutrophication and subsequent ecological imbalances. If the effluent containing the nutrients is reused rather than discharged, eutrophication can be avoided without costly nutrient removal technology. Phosphate and nitrogen are not a problem in most reuse situations and would usually be beneficial if used for irrigation of the garden. Resource reuse then becomes a method of pollution prevention as well. On-site treatment, recovery and reuse then makes much more sense, both in the domestic and industrial situation. As the emphasis at the conference will be domestic treatment, I will emphasise the industrial situation in this paper.

Recycling water is not a new concept by any means. It is Nature's own method to ensure that the limited supply of water on Earth is made available over and over again. All water supplies on land originate from rainfall and find their way back to the oceans where they re-evaporate at some time to be recycled onto the land. Overpopulation, agriculture and industry pose a threat to the stability of this cycle and only by creating smaller reuse cycles within Nature's bigger water cycle can we to some extent reduce our devastating effect on the natural environment.

In industrial water reclamation systems, there is also the possibility of recovering or creating useful by-products. A PhD study recently completed under my supervision, was successful in converting starch waste into useful protein. We have also started a programme this year to investigate the recovery of valuable substances from sewage biosolids and animal wastes. We are investigating the use of various organic waste products as adsorbents in the treatment of mining and metallurgical outfalls to remove valuable and toxic metals. These projects simultaneously purify the effluents treated, thereby enhancing reusability.

4 Limiting Pollution

It is not possible for large human populations to have no impact on the environment. The zero discharge principle, although laudable as an ultimate aim, is not a practical option as we are limited by a very basic concept. Most people are familiar with the concept embodied in the Second Law of thermodynamics, which states that energy is degraded from useful forms to heat when used, and that most of this waste heat can never be recovered. When we use a heater or cooker in the home, the energy concentrated in wood, coal, gas, thermal springs, tides, oil, dams and solar panels is converted into diffuse heat, which can never be reused in another form of energy. In using these energy sources and resources, there are always consequences.

This makes it an impossible situation to enforce zero emissions from industry. It is conceptually possible to require that a town obtain clean water from waste water and return solids and nutrients to farms to produce goods, rather than use manufactured or mined fertilisers. To produce clean water requires energy. Water must be pumped, chemicals must be produced, and various treatment processes constructed. All of this requires power, and all of these processes produce waste products.

An example of the above is the use of activated carbon in wastewater purification. Activated carbon is very effective in removing a myriad of pollutants from water. The manufacture of activated carbon requires a raw (organic) source of carbon (e.g. wood or coal) which must be extensively processed to produce activated carbon. This process requires energy, and consumes 90% of the raw source material, which exits the processing plant as carbon monoxide and carbon dioxide plus other impurities, polluting the environment. This activated carbon is used to remove a wide range of pollutants from waste and is typically able to adsorb 10% of its own mass under conditions of use. Therefore, to obtain removal of 1 kg of pollutants, 100 kg of raw material must be processed, producing more than 99kg (after combustion closer to 200kg) of greenhouse gases during its manufacture.

5 Sustainable Energy Production

The First World is a major consumer of energy. While there are a number of countries where the people survive on less than 1GJ per capita per year, first worlders consume 125-300 GJ/y. To provide part of this energy, 10 tonnes of fuel are burned every year for every person in Australia compared with only 0.25 in India. This releases carbon dioxide, nitrous oxides, sulfur dioxide, carbon monoxide and dioxin among many other chemicals into the atmosphere: about 40 tonnes of greenhouse gasses per Australian as a consequence. This is unsustainable and engineers have to learn (and teach) how to reduce this consumption of energy or find alternative energy sources.

Nuclear power is much cleaner than coal, but a catastrophe such as Chernobyl and a near miss at Three Mile Island, have resulted in a huge public opinion backlash and a slowdown in implementation in all but a few countries. Nevertheless, the total death toll at Chernobyl was 17 people, compared with many more that die annually in coal mining accidents and thousands that die from respiratory illnesses exacerbated by coal fired power stations and the global warming resulting from these. Hydro-electric power is clean and cheap, but could have serious ecological consequences. Alternative energy sources are being developed: wind, geothermal, tidal, and solar. Capital costs are an important inhibitor for many of these schemes, but often, they might be good alternatives to power outlying areas. All of these are clean with relatively minor impacts on the environment except for cluttering the view.

The approach to energy supply is extremely wasteful. Our houses, for instance, could be designed to require almost no heating using a passive solar design. Heating is the most important consumption of power in the domestic situation. Using electricity, superficially clean, is particularly wasteful, considering that only 30% of the heat liberated by coal burning is converted into electricity. The cumulative loss by the time it is used to heat our homes, is about three quarters of the chemical energy contained in the coal. Direct burning for heating is therefore much more effective and produces less pollution, although the load is shifted into the cities. A better designed house, using gas for cooking and solar water heating would only need a quarter of the electricity used in a conventional design. This lesser amount could easily be provided, if need be, from small local alternative sources such as wind or solar power.

A very effective system used in Västerås, Sweden, is to use power station cooling water to heat the city. Heated water is circulated through houses, shopping centres and finally under street pavements. Innovative approaches like this and the use of alternative energy sources have kept Scandinavian energy consumption well below that of comparably highly advanced nations.

6 Preventing the Introduction of Feral Species

Another form of pollution is the introduction of foreign species for farming, pleasure or inadvertently as "passengers". Just think of the feral pigs, foxes, cats, lantana and cane toads.
When sea-going vessels are involved, it becomes an engineering matter too. We have seen the devastating introduction of foreign species from foreign ports into our own fragile coastal ecosystems. This has all but ruined the shell fish industry in Tasmania by introducing a "red tide" organism – a toxic dinoflagellate. The Great Lakes in the USA have suffered excessively from the introduction of the zebra mussel from the Black Sea and economic losses due to blockages of water intakes to industry, power generation plants and water works. Estimates of damages and control measures range from $5 to $50 billion. In addition, the zebra mussel outcompetes and threatens local shellfish and has few natural enemies in its new environment.

A PhD study under my supervision has addressed the possibility of using simple filtration or disinfection technology to prevent the introduction of coastal foreign species. Many of the species are large and dense enough for physical removal, but some microbial species would require disinfection. It should also be acknowledged that delays in shipping are very expensive and treatment must be rapid, require little space and energy. It goes without saying that without international enforcement, it should be inexpensive. It has shown the efficacy of a combination of micro-screening (or possibly hydro-cycloning) with ultraviolet irradiation, which are relatively cheap technologies. They are quite compact, rapid and economical. The work has also established that many species are susceptible to low levels of heat treatment. This would make the use of waste heat from the ships engine a viable approach to control of foreign species. All the technologies studied have been adapted for on-board (i.e. on-site) treatment. The research also established some guidelines for sampling and analysis which could be used in establishing legislative guidelines. This work is not only of ecological value, but also of great importance to the fishing and tourist industries and has raised substantial interest both locally and overseas.

7 On-Site Starch Wastewater Treatment with Single Cell Protein Production

Australia converts wheat flour into starch in most of the major cities in order to provide a raw material for the manufacture of a variety of adhesives as well as applications within the food industry. The process, which is essentially a wet one, produces substantial quantities of waste water with high concentrations of organic material. Whilst this material is relatively innocuous, it needs to be treated biologically to lower the BOD before disposal. One company was paying millions in sewage disposal charges per annum because of this high BOD and has spend more millions in installing an on-site anaerobic treatment process at one of their plants. The research described in this paper was aimed at substantially lowering this BOD, while also producing a useful proteinaceous biomass. The investigation was done on bench scale to develop parameters for the design of a pilot plant.

The *starch* waste water had a COD of 12300 mg/L (of which 7900 mg/L soluble), a BOD of c. 9600 mg/L, a TOC of 4550 mg/L and presented a disposal problem mainly as high sewer discharge fees to the manufacturer. A single, non-aseptic fungal treatment process was developed, which not only removed 95% of the BOD and 78 - 85% of the total organic carbon (TOC), but produced a biomass product with a protein content of 38 - 48%, suitable for animal feeds. Different strains of *Aspergillus oryzae* and *Rhizopus arrhizus* were found to be suitable, but the efficiency of conversion of waste to fungi was substantially influenced by the species and strain of organism selected.

Addition of plant nutrients was not essential, but some increase in biomass production could be achieved with phosphate, magnesium and calcium supplementation. An air lift reactor configuration was developed with air spargers and external recirculation resulting in velocity gradients which favoured the growth of pelletised colonies. These are easily harvested and dewatered by screening. Further dewatering could be done with a simple process such as belt pressing.

The microfungi grew exponentially with no pronounced lag phase shorter than 6 h. A biomass yield of 1.30 - 1.44 g of dry biomass/g TOC, a protein yield of 0.55 - 0.67 g of protein/g TOC, and 78 - 85 % TOC reduction was achieved as well as a nearly completely hydrolysis of the starch materials. *A. oryzae* 3863 growth formed clumpy mycelia and compact pellets (Jin *et al.*, 1999c). Compact pellets, and clumpy and coalesced mycelia are the desirable morphological forms for oxygen transfer and biomass harvesting. The fungal biomass products contained 38 % - 48 % protein and may be safe for human and animal consumption.

Both newly designed internal and external air lift reactors (ALRs) are very suitable for the cultivation of the fungal cultures. The external ALR with double spargers appeared more suitable for cultivating the selected filamentous microfungi. The diameter ratio of the downcomer and riser $D_d/D_r = 0.71$ was determined to be optimal for both ALRs. The selected microfungi could be cultivated successfully in batch, semi-continuous and continuous process, but the semi-continuous mode might be most suited to achieve a high productivity and better quality control. Using the new ALRs and precultures in the batch cultures of *A. oryzae* 3863 and *R. oligosporus* 2710, the generation time was shortened by 2h compared with the shake flask cultures, and maximum biomass growth was achieved within a period of 10 and 12 h, respectively. An air flowrate of 0.5 - 1.5 v/v/m was required to maintain the dissolved oxygen level above 50 % of the saturation during the cultivation. Contamination occurring after a long term run (6-10 batches) of the nonaseptic process might be reduced by running the external ALR equipped with a cross-flow microscreening unit. The ALRs had a high bioconversion efficiency of starch materials and a short hydraulic retention time requirement, resulting in producing 4.5 - 6.0 g/L of dry biomass.

Nearly complete removal of suspended solids and 95 % COD and BOD make the effluent suitable for farm irrigation or substantially reduce sewer disposal costs. All the results can be achieved in running the process without pretreatment of SPW, without nutrient supplementation, and without aseptic operational conditions. Unlike bacterial biomass as used in conventional wastewater treatment processes, this biomass has a value of \$200-\$300 per ton, which would not only off-set treatment costs, but make this an opportunity to generate a profit.

The provision of food to 6 billion people is one of the greatest challenges to mankind. In satisfying the quest for food, however, agriculture and fishing pose one of the greatest threats to the environment. The earth has been defaced through deforestation and annihilation of species, all to clear more land for agriculture to grow food for an ever-growing human population. Microbial biomass protein (MBP) growth can be maintained at a much higher rate of food production - orders of magnitude higher than achievable on or in soil. Microbial biomass can double in less than an hour while we know that it takes plants on average days or weeks to achieve the same gain. While the amount convertible from waste organics from the food industry will not save the Earth, it will make significant contributions to pollution control.

8 Treatment of Wastewaters from Pesticide Manufacture

There is concern in Australia about the increasing use of pesticides for crop protection (Schofield *et* *al*., 1998). Pesticide manufacturing wastewater (PMW) is produced during rinsing and wash-down operations at pesticide production facilities and is contaminated with pesticides and other chemicals. Because of the highly heterogeneous chemistry of PMW, treatment becomes particularly challenging and may involve the use of more than one technology. In this work, the potential of ozonation, filtration, coagulation, activated carbon adsorption, and biofilter treatment for removal of pesticides was examined on laboratory scale.

The *pesticide* waste water had a high COD and contained a variety of pesticides, mainly endosulphan 1 and 2, diazinon, malathion, atrazine, simazine, chlorpyrifos and others in a total concentration of c. 1.6 g/L. Normal disposal methodology involves encapsulation and costs several thousands of dollars per cubic meter. The bench-scale research involved ozonation, biological granulated activated carbon treatment, biofilter treatment only and chemical coagulation with microfiltration. A biofilter process without activated carbon was studied in parallel. Both the biofilter and biological activated carbon with coagulation and separation with microfiltation were able to remove about 99% of most pesticides, with the bulk of the removal occurring during the biological treatment stage. A notable exception was simazine, which left persistent residues. The pesticide removal is shown in Table 1 (van Leeuwen *et al., 1999).* While ozonation improved the COD and pesticide removal, it was not deemed an essential treatment component. Even the activated carbon, while improving the pesticide removal greatly, was not essential in achieving adequate treatment goals. The effluent would have been suitable for sewer discharge with costs two orders of magnitude less than encapsulation.

TABLE 1 Improvement in Wastewater Quality with Biological and Biological Activated Carbon Treatment (Concentrations in mg/L)

Substance/determinant	PMW	Biological Treatment	BAC
endosulphan 1	1036	8.0	0.116
endosulphan 2	396	3.5	nd
diazinon	17	0.22	0.048
malathion	74	0.37	
chlorpyrifos	76	4.76	0.0027
heptachlor epoxide		0.191	
atrazine		0.043	
simazine	nd	9.8	6.21
dicamba	1.3	0.224	
2,4-D		0.026	
2,4-DB		0.154	
trichlopyrifos		0.170	
MCPA		0.364	
carbamate pesticides	<0.1	<0.1	
COD	70,000	8000	
TOC	18,000	2000	
total solids	40,000		
total suspended solids	19,400		
chloride	2,300		
alkalinity ($CaCO_3$)	3,600		

Savings in wastewater disposal costs of more than 95% could potentially be achieved after this level of removal of pesticides and organic material, although more research is still required.

9 Conclusion

Centralised treatment and disposal has long been the hallmark of the Western approach to dealing with wastes. This attitude should change as there are too many disadvantages. Taking care of ones own wastes creates responsibilities and opportunities for more effective and environmentally safe waste management.

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