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Review Article

Meeting the Challenge

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The first Chempor Conference held in Lisbon in 1975 under the auspices of the Calouste Gulbenkian Foundation, heralded a regular wide-ranging review of research and development in Portugal and the UK Progressively in later years the Conferences have attracted contributions from other European countries and indeed further afield. There is an increasing awareness of the problems for the environment, notably global warming, brought about by human activities. Recent predictions about the future are dire, particularly regarding food and water for a rapidly growing world population. They represent a substantial challenge to the scientific and technical fraternity. In response to that challenge it is important to keep up to date with technical developments, to meet and keep in touch with coworkers in associated fields, and to cooperate wherever possible. The papers presented at the Chempor and other conferences have made and continue to make a significant contribution to that objective of meeting the challenge.

1. Introduction

For thousands of years humanity has had to cope and come to terms with the challenges of starvation, disease, and conflict. There have been some useful developments over the years in food production (particularly the so-called "Green Revolution" in the 60s) and in medicine. Sadly though the establishment of universal peace seems as distant as ever. Despite the strides in agriculture and disease control, the basic needs have not been met for a large proportion of the people living in the world. With the anticipated dramatic rise in the population in the coming decades, estimated to be at around eleven billion in 2050, the problems of food production and medical care will become even more intense, unless effective action is taken. The provision of clean water for human consumption is also of vital importance in the suppression of disease. Technology has a responsive role to play in meeting this challenge.

In addition to these basic needs of humanity, energy has played an important part in the lives of many members of the human family since the Industrial Revolution, not only in food production but also in aspects of disease control and particularly in the field of transportation. In previous millennia, energy primarily required for food production was provided either by human or animal power. The phenomenal growth in energy usage generally provided by the heat of combustion of fossil fuels (coal and oil) or other combustible, usually carbonaceous, material has led to the discharge of vast quantities of products from the combustion process, notably carbon dioxide. Although there are dissenters, it is believed by the majority of the informed, that the random discharge of these so-called greenhouse gases to the atmosphere is leading to the phenomenon of global warming, bringing in turn changes to the climate. Additional problems associated with industrialisation and a higher standard of living is waste disposal and satisfactory sanitation.

In a UK government document (a summary of a White Paper) entitled "This Common Inheritance" [1] the following points were made; Mankind long believed that, whatever we did, the earth would remain much the same. We now know that this is untrue. The ways we produce everything and the rate at which we multiply, use natural resources, and produce waste threatens to make fundamental changes in the world environment. Nature is under threat. We have a moral duty to look after our planet and hand it on in good order for future generations. That does not mean trying to halt economic growth. We need growth to give the opportunity to live better and healthier lives.

In recent years, though, the issue of climate change has been paramount in the United Nations, the European Union and individual nations, and various summit gatherings. The Kyoto agreement in 1997 pledged to cut the emission of greenhouse gases principally CO_2 by 12.5% (based on 1990 levels) by 2010. At a recent G8 summit (July 2008) a target of achieving 50% reduction in global emissions by 2050 was suggested. In December, 2007, 15000 people flew to Bali to discuss climate change [2]. It was the intention to build on the achievements of the Kyoto agreement and it was considered to be a success with a continuation of the dialogue begun at Kyoto.

The European Union environmental legislation Integrated Pollution Prevention and Control (IPPC) applies separately to different aspects of the natural environment—air, water, waste, and so on. Porteous [3] states that the IPPC Directive, based mainly on UK law, requires major industrial installations to be licensed in an integrated way for controlling emissions to air and water and the management of waste to protect the environment as a whole. The approach encourages industrialists to think about the whole process adopting cleaner technology rather than just adding "end of pipe" controls.

2. Food Production

One of the major problems of attempting to increase food production to satisfy the growing world population is land use and land availability. Tropical rainforests are constantly burnt and wetlands drained to provide land for agriculture—growing crops and rearing animals as sources of food. The use of land for raising sheep and cattle for food, however, is not considered by many as an efficient use of that land. The opportunity of growing two crops per year of edible foods is much more attractive in the light of the growing number of mouths to feed in the world. Together with pollution of water courses and overfishing, many species of wild plants and creatures are being driven to extinction. As a result valuable sources of food and medicine are lost. The alternative is to improve the output from existing agricultural land, which may be substantially achieved by the application of artificial fertilisers and use of herbicides and insecticides with special safeguards. A recent discourse [4] emphasised that billions of people worldwide suffer from "hidden hunger", an insidious form of malnutrition, that can leave children stunted, immune systems compromised, and adults unable to work effectively. The condition results from micronutrient malnutrition caused by their lack in the diet. The poor in developing countries who live mostly in rural areas depend largely on locally grown staple foods like rice, wheat, and corn to satisfy hunger but these provide insufficient nutrition. A world wide organisation "Harvestplus" is dedicated to the development of staple foods rich in micronutrients that rural populations can grow and consume. In order to provide the necessary content of iron, zinc, and vitaimin A, suitable low-cost fertilisers will be required on a large scale.

3. Water

As important as food, if not more important in many ways, is the availability of clean water. Water supplies around the world are heading towards crisis point. Experts are predicting large-scale water shortages over the next 25 years. It is anticipated that two out of three people on the planet will face regular depletion of water supplies. Population increase and rising standards of living, together with pollution, are rapidly diminishing the availability of naturally occurring sources of clean water. Water-related diseases, such as diarrhoea, cholera, tachoma, hepatitis, and intestinal worms afflict millions of people worldwide. Approximately 1.8 million people die each year from diarrhoeal diseases alone, 90% of whom are children under the age of five [5]. Many pathogens excreted by humans and animals can cause these diseases when they are ingested via faeces-contaminated drinking water. These pathogens and other contaminants can be physically removed by filtering, adsorption, or sedimentation, and they can be rendered innocuous by chemical, heat or u.v treatment.

In developed countries the potable water supply is carefully protected from contamination. In the EU for instance, there are stringent requirements for water quality to safeguard the health of people in respect of microorganisms and toxic substances. Water is usually drawn from rivers or it may be obtained from boreholes in suitable locations by tapping into aquifers. In addtion to serving the public, water has many industrial uses such as a medium for conveyance of wastes, slurries, and wood pulp, as a solvent and as a heat transfer medium principally through vapour (steam), or cooling.

Where sea water is available, desalination becomes a possiblity. In multistage evaporation there are opportunities for efficient energy use and the cosequent implications for global warming. An alternative is the application of reverse osmosis. Koutsakos [6] states that there are not enough chemical engineers employed in this industry.

The disposal of waste water from public sewage systems and industrial use also requires stringent controls, since it is often returned to its source. It has been said that the water in the River Thames is used ten times over in its journey from its source to the sea. In the methods available for the treatment of water the application of physical forces predominate (well known to chemical engineers). In general terms there are three stages. In the treatment of waste water particularly, the primary treatment involves physical operations such as screening and sedimentation that are used to remove the floating and settleable solids from the water. Secondary treatment involves biological and chemical processes to remove organic matter. A final treatment is applied to remove any trace constituents that still remain in the water.

Filtration is widely used for the preparation of public water supplies—including traditional sand filtration and membrane fitration. These have application outside the water industry such as solvent recovery and the production of potable water from sea water. Papers presented at the Chempor Conference in 1975 described the disinfection of water in the 1974 epidemic of cholera [7] and water demineralisation [8].

4. Waste Disposal

Substantial industrialisation and improved standards of living have given rise to the production of a wide range of waste materials, from manufacturing to domestic and retail outlets. It is usual to classify waste disposal into three categories; landfill, incineration, and recycling. Landfill is subject to tight scrutiny because of the risks to public health, through the contamination of ground water. Disposal at sea, consisting of long-term persistent noxious substances lower the amenity of an area due to smell, visual degradation, and possibly noise, so is not readily acceptable. Flammable waste incineration particularly domestic waste, has been practised for many years. Because of the problem of emissions notably CO_2, the technique has come under critical assessment.

The best option is to recycle, but this is no straightforward option because it is likely to be a mixture of components that may need separation, which can be labour intensive. In order to overcome some of these difficulties it might be possible to recycle in a different way, by the incorporation of plastics and broken bottles in building materials, for instance. At the first Chempor Conference in 1975, Bridgwater and Bessant [9] presented a paper entitled "Plastic waste-disposal or recovery?"

5. Energy

Increased industrialisation and improved living standards that have been achieved in many parts of the world have been largely based on the availability of different forms of energy. The traditional acquisition of energy going back over countless generations has been through combustion to provide heat. Combustion is still an important component in the scheme of things, and is likely to remain so, but the associated technology has become more complex due to the concern for the effects of the associated emissions on the climate, already discussed.

The first priority in achieving minimum output of greenhouse gases is effective energy management. Chemical engineering technology is uniquely placed to make a substantial contribution to effective management to maximise energy efficiency. A basic requirement is effective design, not only in respect to the combustion process itself, but in achieving maximum heat transfer. A recent simplified study [10] of the water-cooled steam condensers on a 550 MW coal-fired power station, demonstrated that a 1 mm thick biofilm on the condensers resulted in an increase of the CO_2 discharged to atmosphere of 6.2 tonne/h. Although this may be considered to be a large additional CO_2 discharge, it represents only a relatively small proportion of the total emission. Nevertheless, if the biofilm formation could be reduced or even eliminated altogether, it would make a significant contribution to reducing the effects of emissions.

Effective control of the accumulation of microbial biofilms can be achieved by the use of biocides. Chlorine has been the preferred biocide for many years on account of its availability and relatively low-cost. Chlorine however represents an environmentally unacceptable pollutant when the water is discharged back to its source. Cooling water is usually taken from a natural source such as a river, lake, or the sea. Under these circumstances the residual chlorine is a danger to living plants and creatures in the water. Furthermore chlorine reacts with organic material to form carcinogenic compounds that are clearly a danger to humans who may come into contact with the water, particularly if it is used for drinking purposes. As a result, alternative, environmentally friendly biocides are available that are continually being improved. The method of dosing, continuous or intermittent, may affect the overall effectiveness of biocide application.

Similarly heat exchangers that recover the heat from hot combustion gases can become fouled with deposits of mineral matter originally contained in the fuel. If steps are not taken to reduce or eliminate these unwanted deposits, the efficiency of heat recovery will be jeopardised, so for a given heat requirement both the fuel consumption will increase and the production of CO_2 will increase.

The reduction of surface fouling in heat exchangers, by good design and suitable control techniques, can make a substantial contribution to a reduction of greenhouse gas discharged to the atmosphere from combustion-based systems. Tackling the problem of heat exchanger surface fouling has been a top technological priority in recent years, particularly since the so-called "oil crisis" in the early 1970s. Improvements to heat exchanger design in respect to fluid velocity and temperature distribution, have made significant contributions to energy conservation. The use of helical baffles in shell and tube heat exchangers [11] and the use of inserts in the tubes [12], to improve the opportunity to remove deposits, are examples of technical advances in design. The material from which a heat exchanger is made and its quality in terms of roughness, have also come under the designers' scrutiny.

Attention to operational managemement to ensure that the design requirements such as flow velocity and temperature distribution are maintained is also an effective tool in maximising energy transfer. The use of modified surfaces and coatings to prevent or reduce surface fouling is also a possibility, although cost and durability have to be carefully considered. The use of additives, as with cooling water, is an option but its presence may not be acceptable in certain products as it may be considered an impurity. This is of particular significance in the processing of food.

In addition to these aspects of energy management, it is possible to reduce emissions by capturing the CO_2 and storing it, usually below ground in deep disused mines and the like. An underground carbon storage facility has recently opened in Australia [13]. The CO_2 originates from a natural gas well, not from a combustion process, but the principle is identical. The storage facility consists of rock formations 2 km below the surface with an estimated capacity of 10,000 tonnes of greenhouse gas. However such a capacity would not be sufficient for a large 1000 MW coal-fired power station that could have around 8 Mt/year CO_2 emission.

The process is most cost effective when applied to large stationary sources of CO_2, such as power stations, refining furnaces, and metal smelting, which account for more than half of all manmade CO_2 emissions. Techniques for capturing CO_2 include absorption, adsorption, and membrane filtration. At the first Chempor Conference in 1975, a paper was presented by Carter et al. [14] entitled "The adsorption of carbon dioxide by deep beds of molecular sieve adsorption". Although this paper was principally concerned with a gas-coolant purification system for a high-temperature nuclear power reactor, it did herald the concept of CO_2 capture for storage underground.

Fossil fuels, particularly oil, are running out, with associated higher costs that have recently been in evidence, so that alternative sources of energy will be required. The combustion of waste, particularly domestic waste, can be a source of energy for power generation, but the emissions that include greenhouse gases may also contain other unwanted compounds, that could be difficult to handle. Preliminary work on the use of hydrogen as an alternative source of energy is a possibility since it does not give rise to greenhouse gas emission from combustion. It may also be used in fuel cells that convert chemical energy directly into electrical energy without combustion. Research is being carried out to investigate their use for powering vehicles. The source of hydrogen in the quantities that will be needed and the fact that it is a gas at atmospheric pressure will create major problems. At the present time hydrogen is largely produced by the electrolysis of water; the source of that power may have come from a conventional power station. Research is being carried out on the possibility of using solar thermo-chemical cycles to produce hydrogen without producing CO_2 [15]. There are however technical problems still to be overcome. An interesting application for industrially generated CO_2, resulting from hydrogen generation is for use in actual greenhouses to encourage plant growth and the capture of CO_2 [16]. Other sources of electrical energy that do not generate greenhouse gases include wind power, solar power, river and tidal barriers, sea wave motion, and geothermal energy.

A developing industry, considered to be a replacement for the combustion of fossil fuels, is the production of "biofuel". It is a fuel as the name implies, which is biological in origin, such as methane, biogas, and biodiesel, seen as sustainable supplements to petrol and diesel. These can be a means of reducing carbon emissions.

Biodiesel refers to a diesel type fluid originating in biological sources such as vegetable oils or animal fats. The manufacturing process produces methyl esters (biodiesel) and a valuable biproduct, glycerine, that has many potential uses. Apart from use in vehicle engines there are other applications such as domestic heating oil to reduce or eliminate the dependence on fossil fuel. Such an application would be of advantage in rural areas where there is no access to domestic gas supplies.

Although combustion generates greenhouse gas emissions, it is argued that since it is plant derived, the CO_2 produced is taken up in subsequent plant growth so that the actual pollution is zero, that is, carbon neutral. An alternative is biomass produced from organic materials directly from plants or from industrial processes. Woody biomass refers to wood-type material or less dense material such as straw and tall grass. Nonwoody biomass as the name implies, includes waste from industrial and food processes and specially grown crops such as sugar cane and maize.

Another alternative is biogas, formed by anaerobic digestion of organic materials, generally waste materials such as sewage sludge and waste from food production. The biogas produced is generally a mixture of methane and carbon dioxide with a ratio of approximately 2:1, respectively. It is possible with suitable modification to use it in internal combustion engines or to generate electricity by the usual method of combustion to raise steam to operate turbines.

In an assessment of the potential for biofuels Bourne Jr. [17] quoting a UN report concludes that although the benefits from biofuels are large, an extensive use of biofuels could jeopardise the security of food supplies, resulting in increased food prices. At the present time it is estimated that 25,000 people die from starvation each day. In the light of these kinds of data it is unfortunate that in some parts of the world rain forests and natural habitats are destroyed to provide areas for the production of crops, which are not for human consumption, but to provide biofuel of one sort or another. Sugar is a typical example. It is fermented to produce alcohol as a liquid fuel to replace petrol in specially adapted internal combustion engines.

A compromise that might go some way to meeting this concern about biofuel and food is to utilise the waste produced in food production and agriculture, rather than using the food substance itself for the production of biofuel. Sugar production from cane is a good example of this approach. For many years waste material from cane sugar refining (bagasse) has been used as a fuel for combustion to produce steam and electricity for the refining process, and the surplus electricity has been made available to the local community. In addtion there is waste associated with the harvesting of the cane on the plantation, currently often burnt in situ. This could also be used as a source of energy. It is anticipated that improvements could make the whole process carbon neutral since the equivalent CO_2 emission would be absorbed by the next year growth.

Green algae, waterborne microorganisms, imbibe CO_2 and provided there is sufficient light available they will rapidly multiply to form a substantial mass of growth. They have often been regarded as a nuisance in reservoirs and in places where there are leisure activities. The Chinese authorities for instance, had to clear vast amounts of algae in preparation for some of the boating competitions at the Olympic Games. It has been suggested that algae might be a good source of biofuel since it is easy to grow and removes greenhouse gas from the environment.

Boyle [18] reports that a company (Ineos) in the UK is proposing to produce bioethanol fuel from municipal solid waste, agricultural waste and organic commercial waste. It is claimed that 400 litres of ethanol could be produced from one tonne of waste. It is pointed out that unlike other biofuels there is no choice to be made between food or fuel with this technology.

6. Concluding Remarks

Humanity is facing a huge challenge in respect of the provision of food and clean water to sustain a rapidly increasing world population. In addition there is the need for energy to satisfy the requirements of the growing population in terms of standard of living and manufacturing industry. The examples cited illustrate the tremendous unique opportunity and indeed the moral obligation for chemical engineers, to apply their skills to meeting this challenge. It is in a spirit of optimism and dedication and the cooperation of governments and industrial entrepreneurs, that will ensure success. The whole process will continue to be facilitated by the exchange of ideas that results from conferences such as Chempor.

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Special Issue on Bioprocess Development for Biofuels and Bioproducts

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The increasing pursuit of green technology and renewable resource products has fostered a dramatic interest in biofuels and bioproducts globally. Primarily, this is due to the potentials displayed by biofuels and bioproducts in curbing current global warming issues through sustainable conversions of biomass into valuable consumer products. The development of biofuels and bioproducts creates pathways independent on petroleum but toward a more secure transport and manufacturing future with a lower greenhouse gas signature. In particular, biofuels and bioproducts have demonstrated the capacity to support the growth of agriculture, forestry, and rural economies, and to foster major new domestic industries such as biorefineries to make a variety of fuels, chemicals, and other products. Examples of these products include bioethanol, biodiesel, and biohydrogen for biofuels and a range of bioproducts from low-volume/high-value products to high-volume/low-value products such as biopolymers and renewable chemicals including propanediol and lactic acid. We invite authors to present original research articles as well as review articles that will stimulate the continuing efforts in assessing the potential of a range of new engineering technologies for producing biofuels and other bioproducts, including the economic and environmental impacts. Potential topics include, but are not limited to:

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