Environmental Planning, Management and Technology in Hong Kong

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Environmental Planning, Management and Technology in Hong Kong

Edited by Peter Hills
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Preface

On May 27th 1987, the University of Hong Kong hosted a one day seminar on the topic of "Environmental Planning, Management and Technology in Hong Kong". The Seminar was jointly organised by the University's Centre of Urban Studies and Urban Planning and a number of professional institutions and bodies in the territory, most notably the Hong Kong Institute of Planners and the Hong Kong Institution of Engineers.

The Seminar represented just one in a series of events that took place in Hong Kong to mark World Environment Day (June 5th 1987). It was attended by over 100 delegates and some twenty papers were presented during the course of the day. The Seminar was one of the few attempts made to date to draw together academics and practitioners working in the environmental field in Hong Kong. As such it not only provided a valuable forum for the exchange of information and ideas about the territory's environmental problems but it also served to generate a number of useful papers on some of the specific pollution problems and related policy issues facing Hong Kong.

The Hong Kong Institution of Engineers devoted two issues of its own journal, *The Hong Kong Engineer*, to papers presented at the Seminar. The organisers felt however, that it would also be useful to reproduce these papers, together with some of the others subsequently made available, in the form of a set of proceedings. We hope that the material contained in this volume will be of interest and value to all those concerned about the quality of the Hong Kong environment.

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KEYNOTE SPEECH

Speech by Hon. G. Barnes, JP, Secretary for Lands & Works, at World Environment Day Seminar on Environmental Planning, Management and Technology in Hong Kong, 27th May 1987

I consider myself very honoured to be invited to give a lead address at this seminar on Environmental Planning, Management and Technology which is timed to coincide with World Environment Day. Although a total amateur in every aspect of Town Planning I feel extremely strongly about it, and have always felt that the most lasting damage which can be done to the most people is by approval of bad plans, with which after the planner has disappeared they, the people, must live out their lives. Indeed the acts in my career for which I find it hardest to forgive myself are my part as an inexperienced Assistant District Officer in the New Territories in securing the approval of certain of the urban layouts.

During the last thirty years Hong Kong has moved from relative poverty to quite considerable affluence. When you are poor, bread and shelter are your prime objectives, and until you have these, things like clean harbours, recreation, elections, and cultural halls seem relatively unimportant. This is certainly what life seemed like in the early sixties, the housing shortages in which would be virtually inconceivable to anyone who did not see them. In Tsuen Wan where I worked, we were directly downwind from the Government nightsoil station and from Gin Drinker's Bay dump where the landfill operation certainly did not merit the description of sanitary, which is given to this kind of operation these days. We noticed, we grumbled, but we didn't really mind. Again when we asked for a recreation ground to be provided for the already half-full Shek Lei Estate, the Finance Branch said we would have to await the completion of the estate and the population being there already before planning, let alone building, could start. Wider roads meant less land for bread and shelter, so roads were generally narrow. Our town planners did their best within the limits to which they were restricted but, with the need to achieve what often seem horrific densities of land use, they could do little to protect members of the population from each other's efforts to so secure shelter and bread, and I guess, sometimes a bit of meat too.

The late sixties resulted in the first significant post-war attempts to improve the general quality of living through planning. For the first time standards of provision of facilities including open space were adopted in planning urban layouts in New Towns. In the seventies the planning of the New Towns received a new charter in the form of a determined statement of a policy of balanced development. Landscaping consultants were employed and there was a general determination to achieve a greatly improved environment. The concept of protecting the population against environmental pollution - an expression seldom even heard of in the sixties in Hong Kong - entered in earnest into Hong Kong thinking in the seventies, with the first establishment of EPCOM. Subsequently came the commencement of an environmental review and the employment of professional staff trained in environmental sciences, but, perhaps because we never had any heavy industrial base, Hong Kong never had the type of crises experienced in some other countries which forced it into drastic and comprehensive action. So Government planning was only gradually affected by thinking more specifically devoted to pollution control and one must accept that the full implications are only now being fully grasped. Even some now obvious mismatches of land-user, for example the contiguous housing estates and petroleum storage farms in Tsing Yi, did not seem a bar to the location of these same estates during the great public housing drive of the seventies. Again the noise pollution implications of some of our flyovers were seen as necessary evils in the tight tussle between competitive uses of that time. This was not merely Government thinking moreover. I am quite confident that the majority of the public, enlightened and less so, would have subscribed to that thinking, that is to say that basic housing and transport were critical to a struggle to survive, and that in Hong Kong a certain price in the environment had to be paid.

Why then has thinking changed on these matters? Why have we all been awakened to a realisation that the environment in which we live is as great a determinant in the quality of our lives as the more material goals we have been pursuing since the sixties. I think it is two things: first and foremost is that we are generally much better off in terms of housing, transport and even money in our pockets than we were twenty or even ten years ago and can afford to think about quality. Secondly, our improved standard of living exposes the poorer qualities of our life, even if the former was gained primarily at the expense of the latter. We are, moreover, far more aware as a community of the pressures in the world outside for a better environment, and these pressures have increased quite enormously in this period.

Where then does this leave us at this stage? With our existing density of land use we cannot immediately aspire to the same standards of environment as those enjoyed in some other countries with more usable land. And with so much invested in land and existing infrastructure and buildings we cannot achieve improvements other than through a long and systematic programme of replanning and adjustment. In these circumstances I believe that the main objectives should be:

(a) The segregation of polluting industry. We have been extraordinarily fortunate that in quantitative terms, there is less seriously polluting industry than in many other countries, but, on the other hand, because most of our industry operates in multi storey buildings constructed for rent and sale, and there has always been a philosophic reluctance to dictate who should do what and where, our polluters are more totally mixed up with other industry and land users than is normal elsewhere. So segregation with others involves moving out factory operations from whole buildings or single floors, and it means the establishment of separate factory areas for them where they are not in a position to pollute anyone else. I think this is achievable for what one can call small polluters, whose total load may be manageable if removed from residential areas. I understand that it is on the way to achievement by Singapore, which uses its whole land area well. But for very major polluters we must segregate and reduce the overall pollution load or close them down.

(b) I am sure that we must little by little do everything we can to remove what are known as the potentially hazardous installations, that is storage of substances which if they escaped could damage and set at risk large numbers of people. Here the harm done in routine operation to those who live next door is minimal, as they are in fact well protected by the self-interest of those operating the storage, by safety regulations and by their enforcement. I think perhaps the most effective form of protection is the operators' own interest in safety, which is a factor which seldom exists in relation to pollution. And for myself I would rate a higher priority to moving the factory which is contentedly cutting its costs by daily filling up the guts of its neighbours with SO_2 than to the company which has a massive interest, in both financial and legal terms and also in its overall reputation world-wide, in the protection of both its goods and its neighbour from danger. That is why I put this form of safety in a lower priority than pollution, especially air pollution, though I realise that I will be sticking my neck out a long way in doing so, and that the general public, excited by horror stories in the media, may not feel the same way.

(c) The third priority for our replanning is, in my view, the older urban areas. These are as I have said elsewhere before, going downhill quite steadily, and they need a considerable amount of sorting out. I see this being done in several ways. The first is the much mentioned, but alas, still unestablished Land Development Corporation. The contribution it can make is in redeveloping larger blocks of land and streets with a better environment than private developers have hitherto aspired to. But this will not alone achieve even the kind of standards we are now seeking to achieve in the new towns, let alone the standards to which we might expect the better-educated and more affluent Hong Kong citizen of the twenty- first century to aspire. The problem here is density of buildings, of people and of activity. To a certain extent the New Towns programme is helping and will continue to help sort out the density of people. Since 1961 the numbers of people living in the central parts of Central, Western, Wanchai, Eastern, Yau Ma Tei, Mong Kok, Sham Shui Po, and Kowloon City have decreased from about 2.1 million to 1.8 million despite the development of reclamations and other hitherto unpopulated areas in them within this period. This process must continue, but building volume in these areas has increased enormously and no parallel increase in circulation and open space has been achieved, and activities at ground level in terms of pedestrian movement, illicit trading and industrial operations continue to congest our down town streets at levels which seem at least as oppressive as twenty five years ago. The Government's forward development strategy which was announced in 1985 aims that urban expansion to follow the New Towns programme should be on new harbour reclamations at Kennedy Town, Kowloon and Hung Hom Bay. It is quite essential that these reclamations should not be seen as land for grabs, for newly imported population, or for revenue, but as the main means by which over perhaps a very long time the density of building in the older urban districts may be relieved by the removal of buildings and activities from the busier downtown areas and their replacement with open space and circulation areas. In the areas where public housing estates predominate, such as North-East Kowloon, Tsuen Wan and Kwai Chung, similar improvements can be achieved with the replanning of the older public housing areas, although with the larger areas to be planned as a whole, there is now possibility for architectural innovations. Fairly recently I announced the Government's intention to produce a master development plan for the whole of the Metropolitan Area. This will be a statement of policies and proposals guiding the use of new land for the redevelopment of the older areas. The main motivation for such a restatement is environmental.

(d) Fourth, we must have a really good look at the rural areas between the New Towns and the Country Parks. Land use has for various reasons been virtually uncontrolled and many of these areas, apparently prosperous farming communities in the early sixties, are now a mixture of dumps and pigsties and squatter structures. There is no sewerage and few roads and the natural streams are choked with pig and human manure which in turn affects the sea water and beaches around the coast. I think the turning point in these areas will be the banning and licensing of pig farms which will be put into operation in the coming year. The load of manure in the streams has hitherto made any real attempts at sewerage systems quite pointless, but with a reduction of animal wastes, sewerage and septic systems should become a practical, if expensive, proposition and must be considered. But if this is to be successful it must be accompanied by a system of planning control to ensure the sewerage systems are not overloaded and that real improvement is achieved in the local environment. The expenditure implications are considerable; the political implications still more formidable, and I shall be proposing that a substantial working party comprising both officials and unofficials should be set up to prepare a comprehensive plan for systematic implementation.

When you are asked to talk about environmental planning in Hong Kong and one attempts to make any positive statement, one can expect one's audience to divide broadly into two. On the one hand, there are those who will want a far more radical and speedily achieved approach that one can realistically suggest, and who will describe such proposals as seem possible as simply cosmetic. There will be the others, usually with far greater experience of land and planning matters, who will see attempts at even the scale of urban surgery suggested here as being impracticable in financial and political terms. And the difficulties and patience and financial resources needed are formidable indeed, making green field New Town development look rather like child's play. As something of an old hand, but with a few ideals remaining, I cannot help sympathising with both sides, but I sincerely believe that Hong Kong must attempt and succeed in such surgery, however painful, and that the time is right to start it is now because:

(a) We have the basic housing problem well on the way to a tolerable solution and we should have the public resources to devote to a steady programme of environmental improvements, provided we give them priority.

(b) The relative and increasing inferiority of the urban environment and the environmental mismatches in our midst are beginning to obtrude to the extent which people will find intolerable.

(c) We still have some opportunities in terms of land to sort out the greater part of our problems.

I have spoken in general terms about environmental planning because it is probably about the greatest contribution which the Government can make to the quality of life in the community. I fully realise that there are other and more detailed aspects of environmental planning and management which are also important but I am confident that they will be covered by people who know far more about them than I. Since his arrival the Governor has made several statements which show his determination to improve the living environment in Hong Kong, and he is not alone in either the Government or the community in his determination. The organisation of today's seminar is an extremely constructive move, and I am sure it will be treated constructively by those involved in it. May I now wish you all a truly productive day.

Part One

Environmental Planning and Management

Environmental Protection - Hong Kong 1987

Stuart B. Reed

Introduction

The pressure on the environment in Hong Kong is mounting[1]

Over the past decade Hong Kong's population has increased by over 20 per cent, the number of road vehicles by 40 per cent, the number of visitors by 115 per cent, electricity consumption by 128 per cent. In real terms, over the same period, GDP has increased by 95 per cent, Gross Domestic Fixed Capital Formation by 95 per cent, and the volume of domestic exports by 128 per cent.

These impressive statistics reflect the continuing development of Hong Kong and its economy as well as the increasing affluence of the population as a whole

Welcome as these developments and this progress must be, they all add up to a dramatic increase in the pressure on our environment over the past decade.

Increased industrial production, more tourists, more cars and lorries, greater electricity consumption, more roads, more construction of new housing and commercial buildings, all these inevitably lead to the production of greater quantitites of wastes or potential wastes of all kinds as well as increasing pressure on the limited amount of space available for development and open space. The wastes may be in the form of solid packaging material, debris from demolition, construction and site formation, liquid effluents and chemical sludges from factories, sewage from domestic premises and hotels, gaseous combustion products from road vehicles and power stations, and so on.

The other environmental implication of the statistics, if experience elsewhere in the world is anything to go by, is that the increased affluence which they reflect will lead to greater concern for the quality of the environment on the part of the community as a whole. The creation of District Boards in 1980 would be expected to provide a more effective channel for the expression of this increased environmental concern and there is clear evidence that this beginning to happen

We have a situation therefore in which, on the one hand, the pressure on the environment in Hong Kong continues to increase and, on the other hand, the pressure from the community for an improved environment is likely to build up substantially over the coming years.

The response to this situation by the Government has been on a number of fronts, primarily:

- institution building to provide improved and strengthened organisational arrangements for environmental protection;
- introduction of a comprehensive environmental monitoring programme to provide objective data for policy development and for new programmes;
- improved legislation and associated control programmes;
- provision of improved facilities for the collection, treatment and disposal of wastes;
- strengthening the arrangements for preventing new problems, through planning against pollution; and
- creating a greater environmental awareness amongst all sectors of the community, including professional bodies such as the HKIE, HK Institute of Planners, and the HK Institute of Architects.

In addition to this response by the Hong Kong Government, the academic institutions in Hong Kong have greatly expanded their activities in environmental matters, as is clearly reflected in papers published in the May and June 1987 issues of *The Hong Kong Engineer*. These papers report the results of research projects on environmental problems ranging from the treatment of pig wastes and disposal of chemical wastes, to radiation from soil and noise from road traffic. The papers refer also to the expansion in the number of pollution control and other academic courses relevant to environmental protection that are now available or shortly to become available at the Universities, Polytechnics and technical colleges in Hong Kong. Also, the environmental content of the syllabi for biology and other subjects in Hong Kong's schools has been much increased in recent years.

What follows in this paper is a brief description of the various ways in which the Hong Kong Government has responded during the past decade to the growing pressure on our environment, and of plans for the future.

Institution Building

The decade has seen a very substantial increase in the number of staff dedicated to environmental protection work and a progressive rationalisation of the institutional arrangements for environmental protection within the Government with the creation of:

- the Environmental Protection Unit in 1977 with an establishment of 8 (Reed, 1978);

- the Environmental Protection Agency in 1981 with an eventual establishment of 112 (Reed, 1982a);
- the Environmental Protection Department (EPD) in 1986 with an establishment for 1987/88 of 507.

The organisational structure of EPD as at April 1987 is shown in Figure 1.

The Secretary for Health and Welfare has overall policy responsibility for the Hong Kong Government's environmental protection programme. Other important contributors to Hong Kong environmental protection work include the Electrical and Mechanical Services Department (EMSD) which operates the sewage treatment plants, the incinerators and the composting plant; the Civil Engineering Services Department which is responsible for the detailed design of sewerage, sewage treatment plants, sewage disposal and landfill facilities as well as the operation of the latter. The Director of Civil Engineering Services is also the statutory authority for the control of construction noise pending the enactment of the Noise Control Bill, when this responsibility will be vested in the Director of Environmental Protection (DEP). Likewise, the controls on ventilation system noise exercised currently by the Regional and Urban Services Departments will pass to DEP when the Noise Control Bill becomes law. These departments are responsible in addition for the vital activities of street cleaning, refuse collection and food hygiene; Marine Department for collecting refuse from boat dwellers, recovering flotsam and dealing with oil spills; Transport Department for controls on noise and exhaust emissions from new vehicles and from vehicles subject to annual tests; and the Royal Hong Kong Police for on-the-road noise nuisances and smoke emissions as well as community noise problems. Much of the responsibility for conservation of the natural environment, including the management of Country Parks, rests with the Agriculture and Fisheries Department.

There is still scope for some further rationalisation of responsibilities in the environmental field, but the basic framework has now been established.

Another important aspect of institution building over the past decade has been the streamlining and strengthening of the Environmental Pollution Advisory Committee (EPCOM). This committee is the main formal channel for the provision of advice to the Government on environmental matters. As established in 1974, EPCOM had up to four sub-committees and, apart from the official-side Chairman, no members of the Legislative Council. In recent years, the committee has been streamlined by elimination of the sub-committees and strengthened by the inclusion of Legislative Council Members, who now comprise 25 per cent of the EPCOM membership.

Important institutional developments have taken place outside the Government with the formation of local branches of the UK Institute of Acoustics, Institute of Water Pollution Control, Institute of Public Health Engineers and Institute of Water Engineers and Scientists. The latter three institutions will be combined into a newly-established Institute of Water and Environmental Management, the Hong Kong Branch of which will be inaugurated on the 4th June 1987.

Agreement has been obtained to also establish an Environment Group within the Hong Kong Institution of Engineers. Arrangements are in hand to hold the inaugural meeting of this group in mid-1987.

Monitoring and Investigations

It is essential that any new programmes and policies are based on objective information about the state of the environment in Hong Kong and that we do not uncritically adopt environmental protection measures that have been introduced elsewhere in the world. It is important also to be able to check on the effectiveness or otherwise of policies that have been introduced, to detect trends that may give rise to a need for new measures and to have available data relevant to the design of new pollution control or waste disposal facilities.

For these reasons, a comprehensive environmental monitoring programme has been introduced over the past decade. It covers water quality (Holmes, 1983) in streams and rivers, in the marine environment generally (Figure 2) and at bathing beaches in particular. Air quality (Kayes, 1980; Chan M., 1985; Bower, 1985) is monitored automatically at six sites (Figure 3), due to be increased to eight in 1987/88, with the data telemetred to a central station in the EPD Headquarters (Figure 4). Two additional permanent roadside sites monitor motor vehicle pollution. A fully equipped mobile laboratory is used for *ad hoc* short-term monitoring exercises covering a few weeks at a time. Detailed surveys of waste arisings (Reed, 1984; Boxall and Yung, 1984) were initiated by the then EPA in 1981 and these have been carried out each year since then. Noise monitoring (Brown and Lam, 1987) is mainly on an *ad hoc* basis in relation to particular noise problems (Brown, Chan R. & Chan H.F., 1985) or planning exercises.

Specific investigations to provide data for the development of new programmes and policies are carried out when needed. Recent ones of significance include surveys of toxic wastes arisings and the use of poly chlorinated biphenyls (PCBs), as well as investigation of the performance of:

- package sewage treatment plant;
- red tides (Holmes & Lam, 1985);

- well-water quality;
- piling noise (Kwan, 1986);
- asbestos in the air;
- lead in dust;
- the economic implications of the control of industrial noise and piling noise;
- agricultural wastes (Hoare, 1987) and liquid effluents;
- the feasibility of marking treated secondary effluents with methylene blue (Chung *et al*, 1986); and of
- the development of locally-applicable techniques for the co-disposal of certain toxic, hazardous and difficult wastes with 'run of the mill' municipal refuse.

Legislation and Its Enforcement

Over the past decade three new ordinances have been introduced, on:

- Waste Disposal(1980);
- Water Pollution Control (1980); and
- Air Pollution Control (1983).

A draft Noise Control Bill was issued in March this year for public comment and, subject to consideration by the legislature, should become law before the end of 1987. In the interim, noise controls are exercised under the Summary Offences Ordinance (construction and community noise) and the Public Health and Municipal Services Ordinance (ventilation system noise).

Dark smoke emissions from boilers have been subject to control since 1959 under the Clean Air Ordinance and more recently under the Air Pollution Control Ordinance (Figure 5). Introduction of the latter has allowed the enforcement programme to be extended to nuisances created by all types of air pollutant. Air Quality Objectives were gazetted in January this year for the Harbour and the Tsuen Wan/Kwai Chung Air Control Zones. Work has started on the management plans which are aimed at achieving these objectives.

A new scheme starting in 1987/88 is planned to crack-down on smoke emissions from road vehicles, using the existing provisions of the Road Traffic Ordinance. Also implementation of the Water Pollution Control Regulations in the first Water Control Zone - Tolo Harbour and Channel - commenced in April 1987. The control of liquid effluent emissions under the WPCO will be supplemented in the Tolo Harbour area and elsewhere during 1987/88 by more stringent enforcement of the controls on drainage connections under the Building Ordinance. Two teams from EPD will carry out back-tracking and other work to detect illegal connections and a complementary team from the Buildings and Lands Department will follow-up to ensure that illegal situations are rectified.

Also it is expected, subject to endorsement by the legislature, that during 1987/88 new controls on agricultural wastes, on toxic, hazardous and difficult wastes and on waste treatment and disposal facilities will be introduced under the Waste Disposal Ordinance. Also new controls on major sources of air pollution - termed specified processes - will be introduced under the Air Pollution Control Ordinance.

Slightly further ahead are tighter controls on road vehicle emissions such as smoke, carbon monoxide, oxides of nitrogen and hydrocarbons, and new controls on road vehicle noise. Also needed is a new strategy for water pollution control which will allow the existing controls on liquid effluent emissions to be extended quickly to the major polluters in the remainder of the Territory, and possibly an Environmental Assessment Bill.

Whilst there is still a need to develop new legislation on some aspects of pollution control and environmental protection, the enforcement of existing legislation is clearly a priority on which it will be necessary to place much emphasis during the next few years.

Waste Disposal Facilities

In order to cope with the increasing amounts of wastes and potential wastes associated with our growing population, our expanding industrial production and commercial activity as well as our growing affluence, it has been necessary to invest more and more in facilities for the collection, treatment and disposal of wastes.

Capital investment in public sector pollution control facilities has grown over 400 per cent in the past decade as shown in Figure 6, despite a recent fall-off due to the completion of certain major projects. This has included ten sewage screening plants, five primary treatment works and schemes, four secondary sewage treatment works (Figure 7), the construction of sanitary landfills (Figure 8), a composting plant and an incinerator. Altogether over 1,000,000 tonnes of sewage and 8,000 tonnes of solid wastes are dealt with everyday by these facilities.

The wastes that are catered for on a day to day basis by these facilities will not go away. They are an integral feature of our industrialised society and, despite the considerable amount of resource recovery and recycling that already takes place in Hong Kong (Lei P.C.K., 1985), the quantity of waste generated will not only continue but will continue to increase. It is essential, therefore, that long-term plans are laid (Reed, 1984; Hoare and Boxall, 1986) for the environmentally ac-

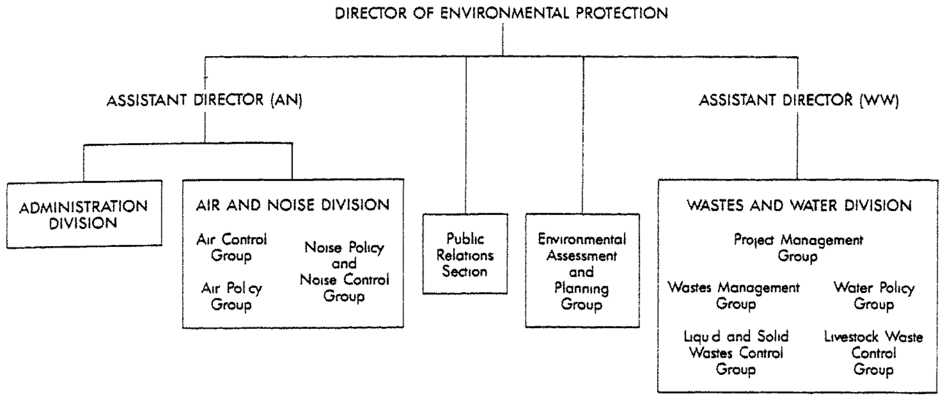

Fig 1 Environmental Protection Department organisation as at April 1987

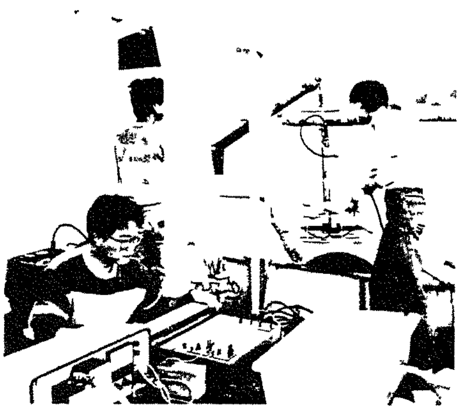

Fig 2 EPD staff using a multi parameter analyser to check on water quality as part of a comprehensive water quality monitoring programme

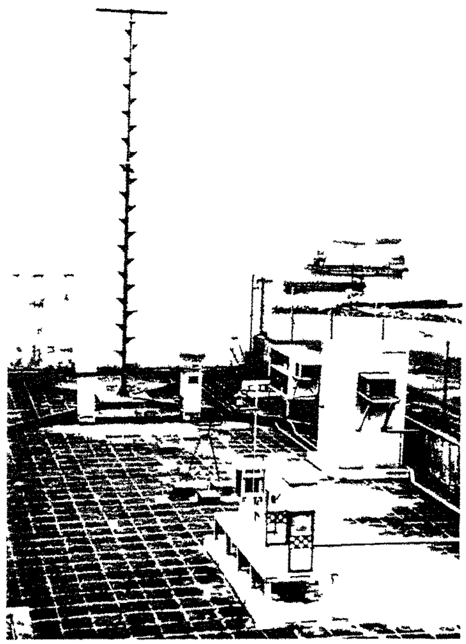

Fig 3 Automatic air quality monitoring site at Junk Bay New Town measuring a wide range of air pollutants and meteorological parameters

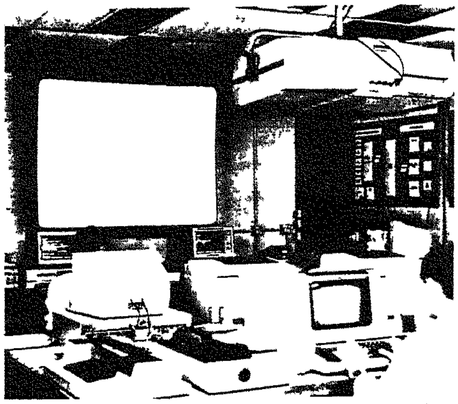

Fig 4 Air quality monitoring control centre at EPD laboratories showing real time control centre display of pollution levels at various monitoring sites

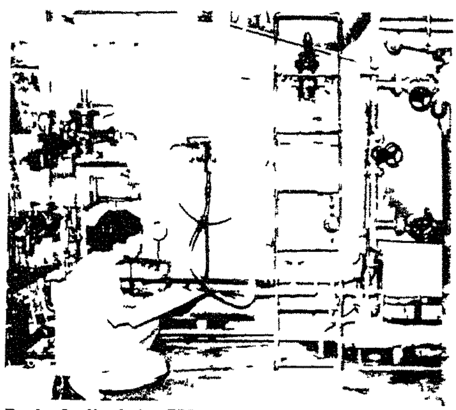

Fig 5 Staff of the EPD's Air Control Group inspecting combustion plant to guard against excessive smoke emissions

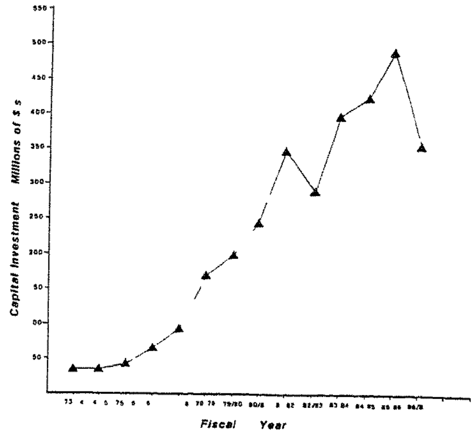

Fig 6 Public Works Programme expenditure on pollution control facilities over the past decade

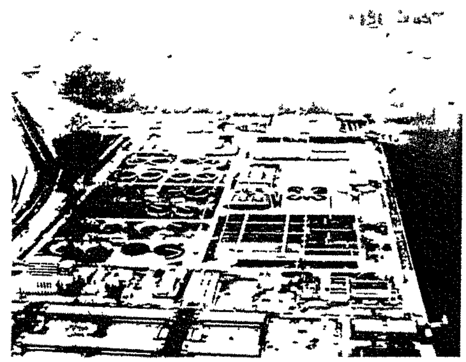

Fig 7 Secondary sewage treatment works serving Shatin New Town & Ma On Shan operated by EMSD

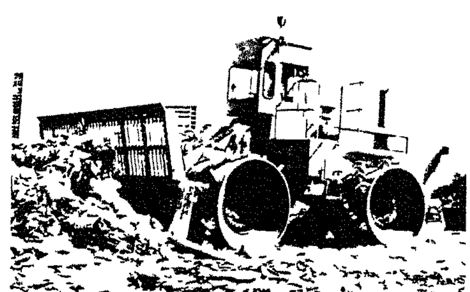

Fig 8 A steel wheel compactor at work at the Junk Bay Landfill operated by CESD ensures improved landfill characteristics

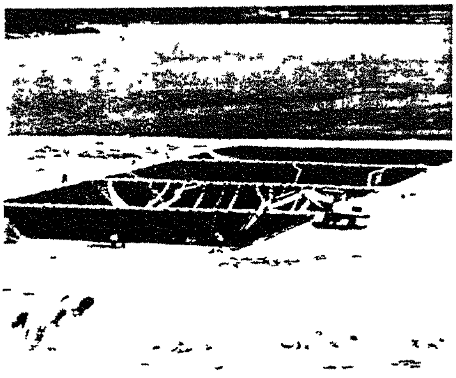

Fig 9 Giant test cells at the Junk Bay landfill site being used to explore the possibility of co disposal in Hong Kong

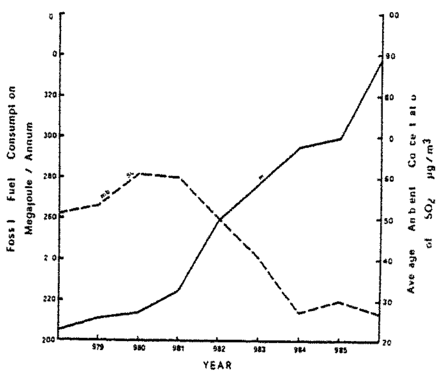

Fig 10 Ambient sulphur dioxide levels fall despite substantial increase in fossil fuel combustion over the past decade

Fig 11 The PF-A lagoons (shown here under construction) and the Castle Peak power station itself have been subjected to comprehensive environmental impact assessment (Photo courtesy of China Light & Power)

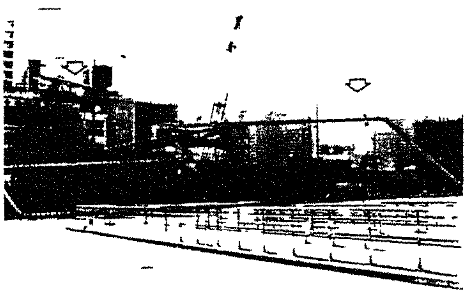

Fig 12 New residential accommodation being developed cheek by jowl with industrial buildings is likely to lead to persistent complaints of pollution and tougher controls on adjacent industries

ceptable and economic disposal of these wastes. This means increased investment will be needed to cope with the growing amounts of waste and to produce the improvements in disposal arrangements that are necessary to adequately safeguard our environment.

From April 1986, EPD has become the responsible authority for the planning of waste treatment and disposal facilities.

The cornerstone for the planning of future facilities for the treatment and/or disposal of the general run of domestic and municipal wastes is the computer-based Hong Kong Waste Management Model (Hoare, Boxall & Wong, 1985). The model has proved invaluable as a tool for optimising the provision of future waste disposal facilities and has led to a strategy that is expected to cope with general municipal wastes in Hong Kong for the next 30 to 40 years.

The strategy is based on three landfill facilities known as the South East, North East and Western New Territories' landfills: SENT, NENT, WENT. Environmental impact assessments and preliminary design studies are in hand on the WENT and NENT facilities which will have a capacity of approximately 50 and 35 million cubic metres respectively, amongst the largest in the world. The SENT facility will be developed when Junk Bay Stage 2 landfill is completed.

These massive landfills will be fed by barge or bulk road carrier from refuse transfer stations, perhaps seven in all, located throughout the Territory. The first of these will be at Kowloon Bay and consultants commissioned by EPD are currently working on conceptual designs and the contractural arrangements for this facility to be designed, built and operated on a turnkey basis by the private sector. As these facilities come on stream, it should be possible to phase-out the large municipal incinerators which have been an eyesore in the harbour area and unwelcome neighbours for many years. The present plan is to phase out Lai Chi Kok by 1990 and Kennedy Town by 1992.

Certain categories of wastes require special consideration because they are toxic, hazardous or simply difficult to handle (Stokoe,1983, Stokoe, 1985). Surveys indicate that wastes in this category amount to approximately 40,000 tonnes per year, not counting pulverised-fuel ash (PFA) and agricultural and other sludges. A two-pronged strategy has been developed for the treatment and disposal of these wastes. This involves co-disposal or treatment at a chemical wastes treatment plant followed by re-cycling or co-disposal. The feasibility of co-disposal in Hong Kong, generally the least-cost option, is currently being explored by consultants commissioned by EPD (Figure 9), and their report is expected in October 1987. Also, the conceptual design of a chemical wastes treatment plant and the contractual arrangements to enable this facility to be designed, built and operated on a turnkey basis by the private sector, are being addressed by the consultants.

The aim is for the plant to be on stream by 1990 so that, together with co-disposal, sufficient facilities will be available when these wastes will have to be notified to and disposed of as directed by the control authority under the Waste Disposal Ordinance.

A further category of wastes of growing importance are sludges from potable water treatment works, sewage treatment and agriculture. The volume of sludges from all sources is expected to grow from the present level of 2,000 to 8,000 tonnes per day during the next decade. One of the major sources of sludge at the present time is the Shatin Water Treatment Works. This sludge is discharged into the Shing Mun River and comprises 12 per cent of the organic load on this already heavily polluted waterway. Planning and design studies in hand are aimed at making available by 1989 an alternative method of disposal for the alum wastes from that treatment works as well as for the sludge from the Shatin Sewage Treatment Works and pig waste sludges arising from the agricutlural waste control programme.

The current sewage disposal strategy is based on a 1971 consultant's study Since that time much has changed, not least the capacity of Hong Kong waters to absorb polluting loads, which has been reduced by successive reclamations. This, and a number of other factors such as the proliferation of large and small developments in the New Territories without access to main sewerage, the widespread incidence of illegal connection of industrial effluent outfalls to surface water drains and the increasing demands placed on bathing beaches, led EPD to initiate a review of sewage disposal strategy as well as the preparation of sewerage master plans for specific areas such as East Kowloon. Work on the latter commenced in January 1987 and is expected to be completed by December 1988.

The review of sewage disposal strategy is expected to commence towards the end of this year. The intention is that the computer-based Water and Hydraulic Model for Victoria Harbour (WAHMO), which is being developed for assessing the implications for water quality of proposed container berth relcamations, can be adapted to provide a logical and systematic basis for the sewage disposal strategy in much the same way that the Waste Management Model has served this purpose in the development of the Waste Disposal Strategy.

The overall aim of the review of sewage disposal strategy is to identify a number of discrete packages that can be included in the Public Works Programme over the coming 10 to 15 years and which, taken together, will provide a long-term solution to the pollution of our marine environment.

One final category of waste that should be mentioned here is pulverised-fuel ash (PFA) which is the ash produced from coal, pulverised before being burned to generate electric power. In principle, this material should not be a waste since it has many beneficial uses such as in reclamation, highway embankments, as a cement replacement or feed stock in cement manufacture, for grouting and for making building blocks. In practice, in Hong Kong and world-wide, it has not proved feasible to make beneficial use of all the PFA produced in the course of electricity generation and additional measures have had to be introduced or are planned.

In the case of the ash from the Tap Shek Kok power station, which currently amounts to 1800 tonnes per day and will rise to 3200 by the mid-1990s, that part of PFA for which no beneficial use can be found is piped as a slurry to the lagoons at Tsang Tsui on the shores of Deep Bay. Given the sensitive nature of the environment in Deep Bay, these lagoons are operated under strict conditions laid down by EPD and incorporate the novel feature of a completely sealed lagoon with decantrate pumped back to the power station to be dispersed, together with the station cooling water, into the deep and fast flowing water of the Urmston Road.

The long-term solution for the Lamma power station, which currently produces 600 tonnes per day of PFA rising to 900 in the mid 1990s, has yet to be settled. An analysis of the options for disposal has recently been submitted to the Government by the Hong Kong Electric Company.

The provision of improved and extended facilities for the treatment and disposal of all types of waste is clearly another priority for the coming decade. This will require a much increased level of investment compared with the past ten years.

Planning Against Pollution

Probably the most significant advances in environmental protection in Hong Kong during the past decade have been in planning against pollution (Ashcroft, 1985; Reed, 1983; Reed, 1985). The many pollution problems that have been avoided or reduced to an acceptable level at the planning stage, often at minimal cost, are seldom, if ever, acknowledged as achievements by the community or the media in Hong Kong. This is understandable because the community and the media are largely unaware of the fact that, because of the effort made to take environmental matters into account at the planning stage, no problems have been created by a particular development. A 'non-problem' is not news.

For example, as may be seen in Figure 10, the consumption of fossil fuels has increased by over 65 per cent during the past decade whilst, as a result of careful location of power stations, control of fuel sulphur levels and the height and design of chimneys, concentrations of sulphur dioxide in the atmosphere have been halved over the same period. This sort of achievement generally passes unnoticed.

Conversely, if a pollution problem develops through bad planning and is then solved, often at unnecessarily high cost, by the enforcement of punitive legislation (Reed, 1985b), then this will often receive public acclaim.

Nevertheless, the most powerful weapon against pollution is planning and much attention has been devoted to this activity in Hong Kong during the past decade.

From a decade ago, when there was little environmental input to the planning process, there are now several mechanisms for ensuring that environmental factors are considered at all levels of the planning process within the Government, from strategic planning to local planning to project planning.

The mechanisms for providing this input include:

- Environmental protection professionals, armed with an impressive array of mathematical models for predicting environmental implications of development proposals (Chung and Kot, 1978; Reed, 1985a), are now included routinely in working groups or steering groups for strategic and local planning studies as well as for specific development projects.
- The guidance provided to planners, engineers and architects through the new Environment Chapter in the *Hong Kong Planning Standards and Guidelines*, which was formally adopted as Government policy in September 1985. The Environment Chapter comprises sections on Air Quality, Water Quality, Wastes Management, Noise, Rural Environment and Urban Landscape.
- The requirement in the Lands and Works Branch Technical Circular TC 12/86 that all items in the Public Works Programme should be subject to environmental review at the stage when they are upgraded to Category B. This arrangement was introduced in August 1986.
- A requirement, often incorporated in land lease conditions, for the submission of a formal Environmental Impact Assessment, prepared in accordance with guide-lines provided by EPD.

A wide range of projects and developments that would otherwise have given rise to quite unacceptable impacts on the environment have benefited from this increased effort on planning against pollution. Examples include: the new coal-fired power stations at Lamma Island (Reed and Woolley, 1982) and Tap Shek Kok and associated PFA lagoons (Figure 11); the Tien Chu Ve Tsin Chemical Industries' chlor-alkali plant on Tsing Yi and the Town Gas plant at both Tai Po and Junk Bay New Town, many new schools and residential developments where a better noise climate has been achieved by improved building location and orientation (Chan R.H., 1985), the new port facilities, particularly the combined Terminal 7; and so on.

The examples given here are all large and well-known projects and developments, but there are countless other smaller ones where early attention to environmental aspects has avoided what could otherwise have been intractable environmental problems.

Inevitably, some projects and developments slip through the net. Many of these were initiated before the full range of measures for planning against pollution was established. There are some recent cases, however, where environmental considerations were over-ridden by other priorities. Often these cases involve the development of residential accommodation cheek by jowl with industries generating much air pollution or noise, or both (Figure 12). Inevitably this sort of decision will lead to a continuing stream of complaints from new residents, which will often result in the adjacent industries being required to adopt more stringent control measures than would otherwise have been necessary. Further consideration of development controls in this type of situation is required.

Promoting Environmental Awareness

There are many reasons why it is important that the general pulbic, as well as particular sectors of the community such as industrialists, planners, engineers, architects and so on, should be alive to environmental issues.

One of the reasons is that many environmental issues involve value judgements, such as the degree to which the health of the community should be protected against the adverse health effects. If we wish to achieve zero health effects of, for example, air pollution, this would mean draconian controls on motor vehicle and factory emissions or even a complete shutdown. The impact on the economy of such measures would result in a drop in earnings leading eventually to an overall reduction in health care. The effect could well be that the health and well-being of the population suffered a net decrease, whereas the original objective of the air pollution control measures was to safe-guard health and welfare We are a long way from getting into this situation in Hong Kong, but clearly a balance has to be struck and an environmentally aware and informed public can help in achieving a reasonable balance by the nature of the pressure it brings to bear on the administration.

Another reason for promoting environmental awareness is that an environmentally aware community is more likely to appreciate the contribution that it can itself make. This ranges from members of the public showing consideration to their neighbours in relation to noisy mahjong games or TV sets, to engineers being more sympathetic than they have been historically to the adverse effects on the environment of their roads, dams, typhoon shelters and the like, or developers appreciating the intractable problems they may create by developing residential accommodation in what is essentially an industrial area.

Most of those who have some working experience of environmental protection in Hong Kong know that the level of environmental awareness here, and the public pressure for environmental improvement, is not anything like as well developed as in most Western European countries. The decrease in membership over the past decade of what was at one time the most active environmental pressure group in Hong Kong, and the complete demise of another, is a disappointing reflection of this state of affairs.

In the past year or so, however, there have been some encouraging developments. A new, internationally-based, environmental pressure group has been established in Hong Kong and there has been a considerable increase in the demand from District Boards for information and action on environmental matters. More resources have been allocated within the Government for the task of improving environmental awareness and, in addition, a project has been initiated this year with Royal Hong Kong Jockey Club funding to provide a number of environmental education and information packages specifically related to the situation in Hong Kong. When completed, these packages will be made available to educational and professional institutions as well as to community groups in general.

Nevertheless, there is a need for further improvement in the environmental awareness of both the community at large and especially of specific sectors such as professionals, industrialists, developers and educationalists.

Conclusion

Much has been achieved during the past decade in terms of establishing new organisations for environmental protection work, introducing new monitoring systems and improved legislation, planning for the future as well as building new pollution control facilities, not to mention the day-to-day activities of disposing of the massive quantifies of the community's waste products and influencing planning decisions to avoid new problems and to create a generally better environment.

Whilst this work must continue there is much more to be done and there needs to be a shift of emphasis in the coming decade.

In particular, more attention will need to be placed on enforcing the environmental legislation that has been introduced during the past few years; more support must be provided at the local level to District Boards in order to solve specific local pollution problems and much greater investment is needed, than in the past, in pollution control infrastructure especially in sewerage and sewage disposal facilities.

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Town Planning and the Environment

K.S. Pun

The Meaning of Environmental Quality

To provide the best possible environment for the present and future population is no doubt a main objective of the town planning profession. This is a common goal among several disciplines which strive for better environmental quality. Nevertheless, to the town planner the term "environmental quality" has a broader meaning.

Generally, views expressed about environmental quality refer to such aspects as air, noise and water pollution and risks posed by various activities to their surroundings. These are certainly environmental problems that concern us. It must, however, be stressed that important as they are, these are only some of the more obvious issues related to "environmental quality.

The "environment" is composed of many other elements. These are equally significant in determining how satisfactory an environment is. In addition to the air he breathes, the noise which disturbs him and the smell from the water which he may see or swim in, a man requires a number of other things in his environment to ensure satisfactory and satisfying living and working conditions. In planning for a better environment, a town planner has also to facilitate the provision for these.

Typical examples are "environmental facilities". These include the provision of adequate kindergartens, nurseries, schools, clinics, hospitals, police stations, fire stations, parks and recreational areas, landscaped plots, civic centres, town halls, community centres, children's centres, youth centres, old people's homes, libraries, playgrounds, sports facilities, markets, shopping centres, parking spaces, transport termini, transport links, employment opportunities and the like. To be effective, many of these have to be made available in close proximity to the users. Further, there are the more territory-wide or region-wide facilities - country parks, picnic areas, beaches, higher educational establishments, cultural complexes, arts and exhibition centres, museums and many others. All these work together to raise the quality of the environment.

Not to be forgotten are some other aspects which are felt most directly by the residents. One of these is the over-crowding and deficiency of facilities inside living-quarters; others include congested development patterns, incompatible uses in the neighbourhood, dirty surroundings including lack of proper refuse collection facilities and services, and traffic congestion. These are immediately seen and experienced everyday by the people.

To achieve a good environment, attention has to be paid to all these environmental components. A balanced view and a broader holistic approach have to be adopted.

Hong Kong's Changing Attitude Towards Town Planning

Throughout the years, the attitude toward town planning in Hong Kong has changed, and changed for the better. Such changes affect the town planner's capability to influence the shaping of the environment. This trend can be seen in the differences in environmental quality in development areas constructed in different periods.

It may not be too fair to judge the conditions in the very old urban development districts on the basis of today's standards. Typical of these districts are Yau Ma Tei, Western and Wan Chai. They were developed at a time when social aspirations and planning approaches were so different that it is in principle inappropriate to compare their environmental quality with that in the more recent urban areas. They are, nonetheless, good examples of what could happen to our environment if development is not carefully thought out or properly managed and if allowance is not made for unforeseeable future demands.

Planned and developed well before the introduction of proper town planning, as it is known today, these areas now suffer from poor environmental conditons. Overcrowding exists both inside and outside living-quarters; the provision of environmental facilities is far below even the minimum standards and scarcely any land can be used to redress the situation; incompatible uses exist in close proximity; many types of pollution can be found.

Some efforts have been made to upgrade the environment in these old districts. One district has been designated for urban renewal; a few others are planned as environmental improvement areas; areas in some of them have been included under the urban improvement scheme of the Housing Society; on top of these are the many private redevelopment projects which, though not being too helpful in improving the general conditions in the district, at least replace old structures with modern buildings and provide some environmental quality has no doubt been raised through these efforts. There is still room for further endeavours.

These successes, limited though they may be, have been partly due to the change of attitude toward the need to provide a better environment. When town planners proposed plans for environmental upgrading as late as the late 1960s, doubts from their colleagues in other related disciplines were not uncommon. Not infrequently town planners were branded as day-dreamers. It is therefore a happy sign that views have gradually been changed and there is now consensus from all quarters in support of the general effort in this direction.

Admittedly when new urban development areas were planned in the late 1950s and early 1960s, more attention was given to the environment, though still insufficient by present standards. Kwun Tong is an example. In its development plan, industrial development areas were located on the leeward side of the town from which they were separated by a main road. Non-polluting industries were proposed. Sites were set aside for the provision of infrastructural and environmental facilities. This is clearly an improved approach.

Good planning intentions were unfortunately not always accompanied by other necessary measures. Well conceived planning layouts were modified by others for various reasons; implementation of the proposed development was not properly coordinated so that the provision of the needed facilities did not always follow in step with the growth in demand; and the lack of effective management and use of control resulted in serious industrial pollution.

By the time the current New Town Programme was launched in 1973, the attitude toward the town planners' ideas had fortunately become much more positive. The principal impetus of this Programme was the 10-year Housing Programme adopted in 1972 as a means to improve the living conditions of a large section of the community in the territory. This latter Programme was hence very much an environment-based exercise. Furthermore, it was realised immediately by the decision-makers that the new towns, in which most of the land required to meet the targets of the Housing Programme would be provided and in which several million of the Hong Kong population would live when completed, should be environmentally attractive places.

In 1971, the Colony Outline Plan was completed and endorsed by the government. It consisted of two main parts: the first being the long-term overall development strategy for Hong Kong; the second, a list of town planning standards and guidelines. This document was therefore the forerunner of the Territorial Development Strategy and the Hong Kong Planning Standards and Guidelines of today. In its second part, standards, locational requirements and guidelines for the provision of environmental facilities were stipulated. Endorsed by a high level government committee on land development matters, these were formulated to guide departments in working out the facilities which must be provided promptly to serve the known population build-up. This part of the Plan was thus a cornerstone in planning for a better environment and represented a major and important change in the approach to and attitude toward town planning in Hong Kong.

Based on these new conditions, two essential town planning principles were adopted in the planning and development of the new towns in Hong Kong. Both of these reflected the desire to achieve a better environment; they also represented attempts to avoid repeating mistakes made in the development of major new urban areas in the past. Partly based on a practice adopted in the planning and development of some new towns in overseas countries, the concepts of "balanced development" and "self-containment" were applied in the new towns in Hong Kong. It was hypothesized that if the necessary environmental facilities and infrastructure were provided to keep step with the growth of demand, as indicated by applying the planning standards to the predicted population build-up, the living and working environment in the new towns would be good and of a higher standard than in the old urban areas. This theory has now proved to be generally correct.

Full balance and self-containment have certainly not been reached at this moment. Complaints are heard every now and then about the inadequacy of some facilities or services in the new towns. However, it cannot be denied by anyone with an objective mind that the environmental quality in these towns is far superior to that in the older districts.

The second principle applied in the construction of the new towns is that development must be effectively coordinated. This is to be achieved by means of a development programme for each town. This mechanism ensures close coordination between the planning, design and implementation of the large number of projects required to provide a good environment, and between the many departments and private organizations building these facilities and providing the services. This is a way to avoid as far as possible past errors in some major new development areas where population and the number of economic establishments grew at rapid rates without adequate associated facilities, resulting in a poor environment

Recent Environmental Laws

In recent years, a series of ordinances on environmental pollution matters have been enacted or are in the process of being enacted. These give the relevant bodies the required powers to control different types of pollution to acceptable limits; they are no doubt very significant measures aimed at improving and protecting the environment.

Several other parallel moves have also been made. A new chapter has been added to the *Hong Kong Planning Standards and Guidelines* to assist the town planners to determine the appropriate location of pollution-generating users relative to sensitive development. Where these guidelines cannot be strictly adhered to, which is not an uncommon phenomenon in Hong Kong with its very limited land supply and compact development pattern, remedial measures are suggested. This additional tool should be helpful to the town planner in his effort to provide a good environment.

A number of studies have been or are being undertaken on major environmental problems. An example is a study on ways to dispose of sewerage from the existing urban areas around the harbour. Instead of direct discharge into the sea, the feasibility of channelling all sewerage into a series of sewage treatment plants along the waterfront for treatment is being examined; another case is a major in-depth hydraulic and water quality study carried out to ascertain the effect of proposed new reclamation schemes on the waters in the harbour before making a decision to proceed with any of these schemes. Today, major development proposals which may have adverse effects on the environment are subjected to environmental impact studies prior to approval being given. These are but some examples to illustrate the increasing attention now paid to environmental quality in Hong Kong.

Administrative capability in the government to enforce the environmental control ordinaces and other measures have recently been strengthened to some extent. The former Environmental Protection Agency has been upgraded to the Environmental Protection Department with additional staff resources to perform its duties and new legal powers through the new ordinances. Unfortunately, the same cannot be said about the town planning side.

Difficulties in Implementation

Noble intentions do not always bear the desired fruit. Though the situation has improved, more positive changes are still needed. The desire to produce a good environment for the population certainly exists. In reality, however, a number of constraints still restrict the extent of success.

One constraint is the difficulty of forecasting the future. Though not peculiar to Hong Kong nor to the environmental improvement work, this issue is particularly significant in this territory due to its rapid pace of development and change. In trying to meet the need of the new town residents, for instance, planners in overseas countries can proceed gradually and monitor the situation carefully at every step before embarking on the next, taking advantage of experience gained. Such as approach is hardly possible in Hong Kong. We not only have to move slowly, step-by-step in the development of any one new town; but we have to develop concurrently and very rapidly three, then six and now eight new towns. We scarcely have a chance to pause. Our planners consequently have to forecast far ahead, knowing full well that it is next to impossible to predict accurately the characteristics of residents far in advance under any situation, not to mention the fast changing conditions in Hong Kong. The provision of environmental facilities must therefore be planned, designed and often built on the basis of the best possible guess many years before the actual residents move into the new towns, otherwise there would be deficiencies of such facilities for a long time. In some cases, it turns out that for unavoidable and unforeseen reasons the actual population characteristics are quite different from the predicted pattern.

Whenever unexpected or unforeseeable needs surface, immediate actions are formulated to remedy or at least alleviate the problems. It is, however, easier said than done. In Hong Kong, the town planner has to meet the requirements generated by a very fluid situation with something physical and quite rigid. For instance, the demand for places in different classes in primary schools moves with the growth of the children's age. It takes a few years to build a school, even if the required site is readily available. By the time the shortage of such places is known, it may be found that the schools already built are not the right types at the right locations; but once they are built, being quite rigid physical entities, they cannot readily be modified to suit requirements. By the time something is done, the problem may have shifted elsewhere, for example from primary to secondary schools. The most pragmatic solution is to adopt temporary remedial measures.

Though less severe in comparison, similar difficulties do exist in the planning for the provision of other environmental facilities. Demands for various types of recreational and sports facilities, welfare services and medical care, just to quote a few examples, change with the fluctuations in the age-structure of the population. These problems are not felt so directly; their deficiencies are thus less conspicuous. They are nonetheless problems which must be resolved in order to provide a good environment.

These problems have to be overcome within the constraint of yet another controlling factor - available resources, especially financial resources. No matter how prosperous a territory is, the quantity of particular resources available at a certain point in time is always fixed and usually insufficient to meet all the competing demands. All dig their hands into the same purse for money to provide environmental facilities deficient in their own districts. Success in one district has to be achieved at the expense of other districts; seldom are the needs in any one district fully met. Some defects in environmental quality are thus inevitable and have to be tolerated.

In most of the older districts, the lack of land is a major hindrance. Since little or no land has been reserved for environmental facilities, to upgrade the environmental quality the government has to resort to either the resumption of leased land or the formation of new land through reclamation from the sea or terracing of hitherto undeveloped hillslopes, where these opportunities exist. Both of these solutions, even if they are practicable, are time- and resource-consuming.

In the real world, a lot depends on compulsion. Men generally put self-interest ahead of most other things. Very few would voluntarily sacrifice personal gains, particularly monetary gains, for community benefits. This applies equally to the enforcement of town planning proposals, many of which restrict the freedom of property owners and users in the way that properties can be developed and used. To ensure that these proposals are adhered to, more often than not statutory power must be bestowed on the appropriate bodies. The difficulty now is that such powers do not exist with respect to many aspects in planning for a good environment.

The Town Planning Ordinance in Hong Kong offers very little, if any, power to the planning bodies to enforce town planning propositions. Section 13 indicates that approved town plans prepared by the Town Planning Board under the Ordinance "shall be used by public officers and bodies for guidance in the exercise of any powers vested in them." Enforcement has to rely on other officers and bodies.

One of these indirect means of implementing town planning ideas is section 16(1)(d) in the Buildings Ordinance. This clause authorizes the Building Authority to refuse approval of building plans showing building works which would contravene any approved or draft plan prepared under the Town Planning Ordinance. This means that control over the use and development of land only comes into play when the owner submits plans to build or redevelop. Indeed, the schedules of uses attached to all statutory town plans indicated beyond doubt that the proposals in the plans are applied only when redevelopment takes place and that the existing development can remain in the meantime; hence, no matter how badly a user or building affects its surrounding or how much the community wishes that use removed, from the viewpoint of town planning procedure there is nothing which can be done about the existing development unless it violates other legislative provisions.

As a way to upgrade the environment, a certain town plan may, for instance, propose to zone some sites used by polluting industries to other uses more compatible with the adjacent development. Such zoning proposals can only be implemented as a when individual owners decide to redevelop the structures on their land. It is usually a long drawn out process. Meanwhile the community has to endure poor environmental conditions.

Another indirect tool to enforce planning proposals is the land lease. In modern leases, conditions are included on the use of land (that is, zonal restrictions), development density, recreational facilities and concession given if these are provided, flat sizes, building heights, parking requirements, landscape plans and other design requirements. Few of the many old leases have clauses of town planning significance. Where they include clauses for environmental control purposes and if these clauses are applied effectively, leases are no doubt helpful in the implementation of planning proposals.

For some modern development sites, master layout plans including the design of the development schemes are required by lease conditions. This practice is effective as a means to ensure more satisfactorily conceived projects resulting in better provision of environmental facilities and a good and attractive environment.

Many environmental aspects are not stipulated in lease conditions. Many industrial lots, for example, are only restricted to "industrial" or "industrial and godown" uses. These obviously cannot be depended upon to enforce planning proposals prohibiting polluting industries in selected sites. Well conceived planning schemes can hence be frustrated.

Neither are town plans themselves entirely effective. Because of the unusual development and economic conditions in Hong Kong, which demand efficiency in adopting changes to cater for rapidly changing circumstances, the town planning system is also designed for flexibility and expediency to allow changes in the use of space with minimum delay. This certainly helps to sustain prosperity. It is achieved through including in the schedule of uses, long lists of uses which are permitted as of right on sites in particular zones. Consequently, land lessees and property owners can vary the use of space without even informing the Town Planning Board or the town planning office in the government as long as they uses within those lists. This approach, no doubt flexible and efficient, neglects the environmental impacts of these uses and is based on the assumption that all uses in the same lists would employ processes without any undesirable environmental effects. This is a particularly important issue with respect to industrial zones.

The current Town Planning Ordinance only authorizes the Board to prepare layouts for "existing and potential urban areas". When this legislation was enacted in 1939, there might have been some genuinely good reasons to confine town planning within the urban areas, a term not defined in the Ordinance. If this phrase is to be interpreted strictly, as tends to be the situation now, unlike planning anywhere else statutory town planning for the non-urban areas in Hong Kong is not always permitted. These areas comprise the largest part of the continuum of the territory of Hong Kong which is a small place; they affect the urban areas and the urban areas affect them. From any viewpoint, it is illogical that the scope of the planning system should be so restricted that a large portion of a territory is left unplanned. This is unfair to the urban areas. Because of this situation, the hitherto attractive environment in many parts of the countryside in Hong Kong, especially those adjacent to main roads, have now been ruined by illegal users. The overall environmental quality in Hong Kong suffers as a consequence.

A further weakness in the town planning scene in Hong Kong is the lack of an effective urban redevelopment instrument. Like any other old cities, Hong Kong has a number of run-down areas, both in the main urban areas and the older parts of the towns in the New Territories. The environmental quality in these areas is low. Whilst the environment in some cases can be improved through piecemeal, small-scale redevelopment, others can only be effectively dealt with by comprehensive urban renewal exercises. Private developers will continue to tackle some of these and the Land Development Corporation to be set up formally by law will deal with others. But who is going to improve the environmental quality in the remaining areas which can be more complicated?

Some Proposed Changes in the System

Many of the environmental problems are the results of an inappropriate distribution of incompatible users in close proximity to each other. Inadequate control over changes in the use of space, deficiency in management, the call for flexibility and expediency, and the low priority given to environment issues in the past cause other problems. Effective measures must be formulated to redress the situation and to avoid similar problems being caused by present-day action for the future.

It is not that the town planner is not aware of this; it is not that he does not want to do what should be done. He does not possess the necessary power, nor is he always supported in his effort by others in related disciplines. If Hong Kong is keen to have a satisfactory environment, not to mention a high-quality one, some changes are needed. An essential change is to equip the town planner with the necessary effective tools.

The Town Planning Ordinance should be overhauled. Formulated nearly fifty years ago when the conditions, types of activities and processes, social aspirations and attitudes, resources available, and many other fundamental factors were so different, this Ordinance cannot meet the needs of today. It requires a complete revision. Something along this line was proposed by a seminar organized by the town planners in 1973. No major changes to the Ordinance have been made since that exercise. It is perhaps time for another such study.

One main change to this Ordinance is naturally to extend the statutory town planning machine to cover the whole territory. A proposal on this has been made by the government and is fully supported by the local professional town planning institute. The proposal has met with an objection from one sector of the community. A renewed effort is called for as a part of the effort to prevent further a deterioration of the rural environment.

Related to this is the need to adopt a policy toward the agricultural sector in the economic structure of Hong Kong. Although most of the population are now employed in the manufacturing and financial sectors, there are still those who prefer farming and the agriculture sector still produces quite a high proportion of our food. The rural areas also provide a good contrast to our very urbanized landscape and a recreational outlet for the urban population. There are still valid reasons, therefore, to retain agricultural activities. A clear policy on this, coupled with more promotion, would encourage more people to farm; and with more farming people farming less land would lie idle, less of the attractive rural countryside would be converted to unsightly development, and the general environment would be improved.

A section on the enforcement of town planning proposals should be added to the Ordinance. It must empower the Town Planning Board to take a number of actions. Statutory town planning proposals should be implemented by the Board with the professional and executive assistance of the town planning organization in the government. A Town Planning Authority should be appointed by law. This system is in fact no different from that already in practice under the Buildings Ordinance for many years. Those parts of other ordinances applied to enforce town planning ideas, such as the building density control schedule in the Buildings (Planning) Regulation and section 16(1)(d) in the Buildings Ordinance, should be transferred to the Town Planning Ordinance.

The Ordinance should also have a section about control over environmental impacts of uses, including changes in the use of existing space. Such uses or changes of use must first obtain permission from the Town Planning Board which may require environmental impact studies to be undertaken where it thinks necessary before decisions on the applications can be made.

As a corollary, the list in the first column (that is, the list of uses permitted as of right) in the schedule of use attached to statutory town plans should be very much shortened. This is particularly essential for the zones with uses which may generate environmental problems. By so doing, more of the uses must seek approval from the Board first; this gives the Board the opportunity to assess the likely environmental effects before any use is allowed to be established.

This additional procedure would reduce freedom and, with respect to some applications, may slow down the decision-making process. The Board and its executive arm will have to be strengthened. A good environment is worthy of this price; this is preferable to the consequences of a bad environment and the cost of subsequent remedial measures. Prevention is always better than cure - not to mention cases beyond cure!

Greater authority should be given to the Hong Kong Planning Standards and Guidelines; this document is generally respected by all departments. Requirements of environmental facilities specified by the town planners for specific development projects are usually broadly met by the developers who can now see the benefits of a better environment in their schemes. Notwithstanding, there are those who regard this document as nothing more than a guide. The document itself stresses that it should be used with flexibility. It should, however, be recognised that this document can only be an effective tool in the effort to achieve a good environment if it has the necessary authority. one possible approach is, perhaps, a reference to it in the Town Planning Ordinance.

Better use should be made of land leases as a tool to control development. This needs the cooperation of the land authority and the determination of the town planner. More specific clauses should be inserted into the leases conditions to indicate clearly and definitely the types of uses allowed and the manner of development permissible on the sites, including the provision and maintenance of environmental facilities. Departments concerned should fully cooperate to ensure that these conditions are adhered to.

To overcome the difficulties in forecasting requirements accurately and in meeting requirements generated by fluid situations with rigid physical facilities, the town planner, the architect, the engineers and the offices responsible for providing the services should work together to derive flexible designs of facilities. For example, primary schools can be so designed that they can later be readily converted into secondary schools, children's centres to youth centres, and community centres to social centres for the elderly. The government has investigated the possibility of building secondary schools on primary school sites, to be used as primary schools in the first instance until the peak demand moves to secondary schools when some of them can be easily converted.

Another area where attention is needed is the redevelopment of old urban areas, particularly where there is a high degree of intermixing of incompatible uses. This is especially important for areas which are unlikely to be touched by the Land Development Corporation or private developers for some time. More determined efforts by the town planner and planning organizations is required to upgrade the environmental quality in these areas, otherwise a substantial sector of the community would continue to suffer from poor environmental conditions.

The town planning organizations in the government must be adequately staffed not only to plan and control but also to monitor development. They should be able to insepct the situation in all districts regularly and to take necessary actions whenever environmental problems are discovered.

Of course, it goes without saying that a closer liaison and cooperation between departments and authorities are absolutely necessary pre-requisites. Those involved should adopt a broader view toward the matter of environmental quality.

Law and the Control of the Hong Kong Environment

M. Downey

Introduction

To date the law relating to pollution control in Hong Kong has been difficult and confusing to follow. This may be partly explained by the fact that those laws which existed had, in the past, resulted from a blend of private common law remedies and public municipal controls. Even the recent replacement of some of these laws with specialised pollution control statutes has in many instances compounded this confusion.[1]

The broad scope of the subject topic is sufficient to make any discussion other than an overview impractical. Particular emphasis however will be given in this paper to the developments which gave rise to the current law and the respective roles of statute and the common law.

Finally, the use of the term "control of the environment" deserves mention. The expression is used here to describe any activity which is designed specifically to protect any combination of public health, amenity and natural facilities which are enjoyed (or deemed desirable), by the community at large. The use of the word "pollution" will be generally restricted to refer to any acts or omissions which tend to undermine that combination.

Background

In 1974 the Hong Kong Government's Secretary for the Environment prepared and submitted a brief to a British company of environmental consultants.[2] The consultants were required, *inter alia*, to make detailed recommendations as to the principles to be included in a unified Environmental Protection Ordinance.[3]

The consultants initially envisaged a 78 week, two-stage programme to complete the project.[4] A report containing general recommendations for action was intended to be submitted at the end of the first phase. Following consultations with the Government a more detailed report, including drafting instructions for the Ordinance, was to be compiled at the end of the second stage.[5]

The scope of the undertaking can perhaps be best understood by noting that the project took three years to complete, was separated into three distinct stages, and resulted in the submission of at least thirteen separate reports and responses.[6]

Having reviewed both the existing environmental legislation and various sources of pollution, the first stage of the investigation culminated in the submission of the Stage I report.[7] Although the survey made many observations and recommendations for action, three particular areas were identified as representative of the unsatisfactory environmental situation.

The report noted that with the exception of a few isolated instances, wastes discharged into the environment remained wholly untreated. The report found that this was largely due to the fact that there were few legal requirements to minimise any resultant detrimental effects. The report further found that such law as existed concerning pollution control, was unco-ordinated and inconsistently enforced. A further conclusion made was that the policy of non-intervention adopted by the Government was partly responsible for the absence of an overall strategy to reduce the effects of pollution.

In order to achieve a controlled environment, the Stage I report made a total of 72 recommendations. These recommendations were further refined and developed in the second stage of the project by the compilation and circulation of six consultative documents.[8] These discussion papers, distributed amongst various Government departments, committees and individuals, outlined a series of more specific proposals and options to supplement those contained in the Stage I report.[9]

The presentation of the Final Report in June 1977 marked the end of the third and final phase of the consultation. This report synthesised the earlier recommendations, responses and discussions by providing specific drafting instructions for not one, but five separate Ordinances.[10] The report also discussed at length various recommendations which were intended to govern the relationship between the control and the enforcement authorities.

Although the consultants' reasoning for the submission of five specialised statutes in place of one comprehensive Ordinance is open to criticism,[11] the Government appears to have accepted this format without opposition.

The draft legislation and the recommendations for action contained in th Final Report embodied a wide range of proposals. One of the most significa recommendations was the suggestion that an Environmental Protection Unit b established in order to co-ordinate a planned and integrated programme of e vironmental control.[12] Although the enforcement authorities would continue t be the responsibility of individual Government departments, the proposed centr control unit would perform a number of roles including: establishing a programme of environmental improvement, establishing guidelines and quality objectives, ensuring the attainment of those standards, and advising on the type of action necessary to monitor and enforce the control programme. The unit was not intended to have any enforcement powers.

The Pollution Control Ordinances

Of the five Ordinances recommended by the consultants in their Final Report, three[13] have now been enacted; a fourth proposal has been recently published in Bill form[14] and the fifth recommendation appears to have been abandoned.[15]

Waste Disposal Ordinance (Cap. 354)

The Waste Disposal Ordinance enacted in 1980[16] came partly into operation on May 19, 1980[17] and May 1, 1985[18] Despite numerous amendments to the Ordinance, even those parts of the statute which are technically in operation cannot at present be legally enforced.[19]

The Ordinance is concerned with three principal objectives. Firstly, the Secretary for Health and Welfare is required to prepare a waste disposal plan. This policy statement is intended to encourage the Government to formulate and adhere to a considered policy framework within which wastes[20] of different types may be collected and disposed. The publication of such a plan is also intended to provide an opportunity for forward planning and public comment.[21] Secondly the Ordinance restricts the collection of wastes to a collecting authority[22] or its licensed agent. Finally, the Ordinance prohibits the unlicensed disposal of waste onto land.[23]

Water Pollution Control Ordinance (Cap. 358)

The Water Pollution Control Ordinance, enacted in 1980,[24] came into operation in 1981.[25] Although technically in force since 1981, it is only recently that the main machinery provisions of the statute have commenced operation with the passage of the Water Pollution Control (General) Regulations.[26] The Ordinance is concerned with controlling the pollution of Hong Kong waters[27] by two interrelated stages. In the first instance the Governor in Council is authorised to designate any area of Hong Kong as a water control zone.[28] Whenever a zone is declared, water quality objectives must be established for that area by the Secretary for Health and Welfare.[29] Such objectives, which specify the minimum water quality standards to be achieved, are to be determined by considering the utilisation of that water which will best serve the public interest.

Once such a zone has been established and objectives have been implemented, the Ordinance enters it second phase by prohibiting particular discharges within any designated areas which are neither licensed nor exempt from licensing. In deciding whether to license a prohibited discharge, the Authority[30] is required to have regard to achieving the water quality objectives "as soon as is reasonably practicable".[31]

Air Pollution Control Ordinance (Cap. 311)

The Air Pollution Control Ordinance was enacted in 1983 and came into operation in the same year.[32] Like the other Ordinances already discussed, this statute still remains largely unenforceable due to the absence of the detailed subsidiary legislation required to give the Ordinance full effect.[33] This Ordinance, which is concerned with stationary sources[33a] of air pollution, is comprised of two main control mechanisms. The first type of control operates in situations where certain types of air pollution have already arisen or are about to arise. The second method of control attempts to minimise the occurrence of air pollution by requiring the licensing of all "specified premises".[34]

In the case of the former control, an abatement notice may be issued, requiring either the reduction or elimination of an air pollutant nuisance.[35] The second method involves a more detailed framework of air management control. Under the provisions of the Ordinance, the Authority is authorised to issue licences subject to such conditions as may be considered necessary to attain the air quality objectives within a particular air control zone.

The Noise Control Bill 1987

The Noise Control Bill proposes to regulate the noise[36] emitted from four distinct sources. Noise from aircraft or vehicular traffic, however, has not been specifically included in the proposal.

The first category of noise restriction applies to domestic premises and public places by prohibiting the creation of a noise nuisance during either prescribed durations (in the case of unspecified noise), or at any time (when specified types of noise-creating activities are being conducted).[37]

Noise emanating from construction sites is subject to a number of controls. In the case of percussion-type piling, a construction noise permit must first be obtained prior to the commencement of daytime activities. Impact piling during the nightime and on general holidays[38] has been expressly prohibited. Other types of construction activities are subject to controls only during the night-time and on general holidays.

A third noise source is defined as "Noise from Places other than Domestic Premises, Public Places, or Construction Sites" - primarily factory noise.[39] A abatement notice procedure has been devised whereby the Authority is empowered to specify the steps to be taken to reduce the noise nuisance level.

The final control operates against "noisy products"[40] by imposing restrictions on their manufacture and use.

Some Characteristics of Pollution Control Legislation

The previous survey which outlined the water, waste air and noise legislation made no attempt to highlight any commonality of legislative approach. Despite the wide variety of objectives and strategies contained within the pollution control Ordinances, there are in fact a number of shared features - both substantive and procedural, which collectively indicate an underlying structural unity.

The granting of licences, which operate to sanction pollution discharges into the environment, represents a basic control mechanism of the specialised environmental legislation.[41] However such a permissive system will, in certain circumstances, affect only some, rather than all dischargers. Thus, although many existing pollution dischargers will be exempt[42] from these licensing provisions, future dischargers will only be able to conduct specified activities and processes if licensed to do so. The licensing authorities have been given wide-ranging powers which include the right to cancel, vary or attach conditions to any licences issued.

The role of the "Authority" is another feature which characterises the control of the environment legislation. Formerly, when the control legislation was first introduced, there were a number of designated authorities responsible for different types of environmental control. Since the Environmental Protection Agency became a separate department in 1986, the Director of Environmental Protection has, as the control authority, assumed some of the responsibilities previously exercised by other Government departments. The Authority, in managing a control programme, is responsible for undertaking a number of roles; such activities include the issuance, variation and revocation of licences and permits, the statutory duty to achieve and maintain the standards laid down in the pollution control policy statements,[43] as well as the power to enforce the provisions of the environmental control legislation.

A decision of an authority is not necessarily final, as the legislation authorises the Governor to appoint the members of an Appeal Board to hear objections from persons aggrieved by decisions of the Secretary or an authority.[44] Although the number of grounds of appeal might be considered reasonable, any opportunity for further appeal from a decision of an Appeal Board, is denied to all parties except the Authority and the Secretary for Health and Welfare.[45]

Prohibited discharges and offences committed contrary to the control of the environment legislation are punishable by the imposition of heavy fines rather than imprisonment.[46] As is usual in regulatory offences, any requirement that an offence needs to be intentionally committed has been dispensed with. Although strict liability offences are normally established indirectly, in the case of two Ordinances they have been expressly enacted.[47]

By way of contrast to the heavy burden of strict liability, the legislation has been arguably generous in recognising many types of statutory defence.[48] If successfully pleaded, a defence would operate to negate any proceedings commenced under the control legislation. Similarly, the Government is liable to pay compensation under specified circumstances where exemptions of licences to discharge are revised or revoked.[49]

The Environmental Pollution Advisory Committee, (EPCOM) a non-statutory body,[50] plays an important advisory role under the three pollution control Ordinances. Notwithstanding that the Committee has been established under a discretionary (rather than a statutory) authority, the control Ordinances require that the Committee be consulted whenever zones, quality objectives, regulations or codes of practice are created by either the Secretary or an authority.

As a general principle of law, the Crown[51] is not usually bound by legislation unless the statute is expressly extended by the legislature so as to require compliance.[52] Under the present pollution control legislation, the Crown has been bound in each particular instance in order to reflect the Government's stated desire of being seen to accept the obligations which it has imposed on others.[53] Indeed, the fact that the Government is the largest polluter in Hong Kong requires that any exception from this binding effect would need to be carefully considered

Other Legislation

In a recent publication,[54] seventeen different statutes were cited as being relevant to the control of waste in Hong Kong. Similar totals were given for other legislation which operated against water, noise and air pollution.

With such a range of legislative controls in operation, it is not surprising that some laws address pollution-creating activities in a more specific way than others In a few limited cases there exists legislation that is wholly concerned with environmental control,[55] but more frequently it results merely as a peripheral consequence of some other more general concern. By way of example, the Bathing Beach (Urban Council) By-Laws, passed under authority of section 109 of the Public Health and Municipal Services Ordinance, are designed primarily to facilitate the overall management of gazetted beaches within the urban area. The presence of just two by-laws which prohibit any activity which amounts to "fouling or littering" is in a sense incidental to the by-laws' numerous other provisions.

The Common Law

The existence of municipal-type statutes which regulate pollution activities has a long history in English law. Although in some circumstances a private prosecution could be commenced by an individual adversely affected, normally the Municipal Authority is the only competent enforcer.

In addition to this kind of public law, the common law has continuously recognised an individual's right to take action to prevent harm or loss to their property. Actions in nuisance or trespass are some of the available remedies where property has been unreasonably interfered with.

Although both systems of law have tended to complement one another, increasingly, legislation has attained priority over the common law in controlling the environment. The requirements of a centralised administration, the pursuit of governmental policy objectives, the difficulty of identifying any one particular offender and the common law's emphasis on the individual ownership of property rather than concern for the interests of the community as a whole, have all contributed to the ascendancy of statute law.

The common law, although supplemented and in some cases even replaced by legislation, continues to be important to the law of environmental control in at least two fundamental ways.

First, the common law provides remedies which are unavailable by statute. In a recent case,[56] the High Court awarded over $200,000 in damages to the owners of a building who suffered reduced rental as a result of the siting of an Urban Services Department "on street" collection point. The court held that a statutory right to collect rubbish did not allow the creation of a nuisance. It further rejected the defendant's claim that the nuisance was the inevitable consequence of what the legislature had authorised the department to do.

Secondly, many important terms used throughout the pollution control Ordinances have not been legislatively defined. Section 8 of the Water Pollution Control Ordinance undertakes to control the pollution of Hong Kong waters by prohibiting the unlawful deposit of any "poisonous noxious or polluting matter". The Noise Control Bill makes it an offence to create a "noise" which either "constitutes a disturbance", "[interferes] with public tranquility" or "causes a nuisance to any person". Even where terms have been defined, in many instances the definition itself remains uncertain. The Air Pollution Control Ordinance defines an "air pollutant nuisance" as any atmospheric dischange which is (*inter alia*) "prejudicial to health" or acts as a neighbourhood "nuisance".

In the absence of any concise statutory definition, a court would invariably need to refer to a variety of sources - including common law principles and previous judicial decisions.

Implications of Environmental Control

The upgrading of the Environmental Protection Agency to that of a department involved a number of changes to its organisation, functions and responsibilities.[57] Although previously responsible for overall environmental quality monitoring and the development of policy and programme proposals, the new department assumed a number of executive and operational responsibilities held by other government departments.[58] Even though there are still a number of other control authorities,[59] the reorganisation of the Environmental Protection Department has resulted in it becoming more centralised and responsible - both as a separate department and as an enforcing authority, than was ever recommended by the ERL Consultants.[60]

Compared with the original preference for a unified Control of the Environment Ordinance, the resulting legislative and administrative framework stands in marked contrast.

The Water Pollution Control Ordinance, in conjunction with eighteen other Ordinances and associated subsidiary legislation,[61] provides the statutory basis for water pollution control in Hong Kong. Of this legislation, the Environmental Protection Department is directly involved with just four of the eighteen items.[62] Other departments and authorities have the responsibility of enforcing the remaining legislation.

There are a number of ways in which the pollution control Ordinances can be selectively applied.

The Air Pollution Control Ordinance applies only to stationary sources of atmospheric discharge - ships, motor vehicles and aircraft are all excluded from the statute's provisions.[63] The Noise Control Bill in the same way imposes no direct control over vehicular traffic - one of the more apparent sources of noise in Hong Kong. In both situations, a vacuum has been created by the legislation controlling the source rather than the type of environmental pollution.[64]

The scope of the pollution control legislation has been restricted in another way. The Water Pollution Control Ordinance only prohibits the discharge of polluted matter into the waters of a water control zone.[65] Under the Air Pollution Control Ordinance, the Authority in issuing a licence for a specified process, has a statutory duty to consider different criteria depending on whether the process is to be conducted within, or wholly outside, an air control zone.[66] In both cases geographical location will be the sole determinant as to whether or not the pollution control legislation applies.

The granting of exemptions represents the final way in which the scope of the legislation can be restricted. Both under the Water and Air Pollution Control Ordinances, dischargers who are in operation on the date when the prohibitions come into force obtain an automatic exemption from the requirements to obtain a licence.[67] Even though exemptions may be revoked or lost under certain circumstances, while they are in operation they effectively protect the discharger from any legislative control.

The pollution control Ordinances, rather than providing short term improvements to the physical environment, will in fact operate mainly to influence and control future planning and developments. The duration required "to achieve and maintain" the various quality objectives established by the Ordinances, will of course, depend to a large extent on governmental policy considerations.[68] In formulating environmental policies, the Government will increasingly be required to accommodate a broader range of community demands.[69] A provision in the pollution control Ordinances which allows the Governor to give directions as to how the authorities and Secretary are to exercise their various powers and duties, could facilitate the expeditious and uniform implementation of any policy changes.[70]

The reliance on different kinds of objective criteria throughout the pollution control Ordinances gives rise to a number of considerations.

The Noise Control Bill makes an offence of any animal "noise" which "interferes with public tranquility". These terms are nowhere defined and presumably a court or even the Noise Control Authority would need to refer to the common law to determine, objectively, just what amounts to a "noise" or "public tranquility". The same Bill however, introduces different criteria for deciding whether, and under what circumstances, a construction noise permit will be issued. Three detailed Technical Memoranda[71] specify an elaborate set of procedures for assessing and determining the acceptability of the maximum noise levels which would result from a permit being issued.[72]

Both the water and air quality objectives established by the Secretary for Health and Welfare attempt a similar method of objective assessment. Any authority, in issuing or revoking a licence has a statutory duty to act in a manner which is compatible with achieving (and maintaining) those objectives.

Finally, the statutory recognition of the possible legal consequences, whenever any code of practice has been breached, should not be overlooked. Under the Air and Waste Control Ordinances, the Secretary for Health and Welfare is empowered to prepare and revise codes of practice which in effect, impose non-statutory controls over atmospheric emissions and waste disposals respectively.[73]

The Crown is bound by the control legislation. The extent of this binding effect is basically the same throughout the Water, Waste and Air Pollution Control Ordinances - the Noise Bill proposes that the Crown be similarly bound. Although the Crown, like any other person, is required to satisfy the various duties and responsibilities imposed by the control legislation, the actual liability of the Crown for non-compliance has been qualified by two exceptions. A third exception protects the Crown from any liability which might result from the issuance of a licence to discharge.

The first two exceptions are interrelated. The Crown, in each of the Ordinances, is exempted from criminal liability for non-compliance and further protected by a prohibition from any other "proceedings". The protection from criminal liability is usually afforded to the Crown on the historical basis that, if the monarch is the source of justice, then it can do no wrong. The additional protection from "any proceedings", would seem to extend the Crown's criminal immunity to apply equally to both civil proceedings and applications for judicial review. If this view is correct, the Crown would appear to be taking additional precautions against the possibility of an individual citizen commencing a private action to compel the Government to either perform its statutory duties or, alternatively, to comply with the relevant statutory prohibitions.

Conclusion

The law controlling the Hong Kong environment, in being comprised of both specialised and ancillary legislation, has resulted in a fragmented approach. Even with the centralised Environmental Protection Department's increased responsibilities, there are still many pollution sources which remain outside the control of this body.[74]

The intention of the specialised legislation to introduce staged controls over pollution will, in the main, affect only a medium to long-term improvement in the physical environment. The extent to which this legislation applies and is in operation appears to have given rise to much misunderstanding - perhaps the responsible Government departments should be more active in promoting awareness of the legislation.

Much of the specialized legislation which is in operation will not affect existing discharges. It seems a somewhat unsatisfactory *modus operandi*, that in order to exert any control over exempt dischargers, resort to enforcing lease conditions or drainage approvals under the Buildings Ordinance needs be made.

As previously stated, the pollution control Ordinances demonstrate a similarity of approach and to this extent are to be welcomed. The method of objectively assessing or minimising pollution sources may, however, give rise to some equally objective criticism - the common law has never claimed to be more certain than statute law, but in this instance the courts have been left with the unenviable task of deciding the difference between "polluted" and "unpolluted" water, "noise" and "noise nuisance", and other such uncertain terms.

Likewise, codes of practice and technical memoranda do not have the status of law but under the Ordinances they have been given the virtual effect of law. The implications of these devices are more than just academic, as any rules which can be arbitrary introduced or modified must in practice be treated with a degree of caution.

Although essential, pollution control legislation alone cannot bring about any improvement to the environment of Hong Kong. The success of the legislation in controlling the environment will, to a large extent, reflect the resources and priorities which are made available for their enforcement. The Government, in making such allocations, will be mindful of three considerations, though not necessarily in this order: community demands, the state of the economy, and a balanced budget.

Notes

1 The extent to which these new Ordinances are in operation or have been implemented continues to cause confusion.

2 The brief, dated 19th June 1974, was addressed to Environmental Resources Ltd (Reference ENV 8/05/05 (TC 30)).

3 The document "Proposals submitted to the Secretary of the Environment Hong Kong Government" submitted in July 1974, provides a detailed outline of the Government's requirements.

4 Paras.9.1 of "Proposals Submitted to the Secretary of the Environment, Hong Kong Government".

5 Para.1.1 Stage I Report.

6 The bibliography contains a chronological list of these documents.

7 The report, submitted in August 1975, was divided into three separate volumes; the Stage I report proper contained observations and recommendations, Appendix A detailed the present and future sources of pollution, and Appendix B outlined the various laws which attempted to control the general environment. The three volumes combined totalled over 700 pages.

8 See bibliography for details.

9 Although the consultative documents dealt with different forms of pollution, there were a number of similarities in the approach. For example, the choice of authorities and controls, the implementation of those controls, the legislative proposals, the organisation and staffing etc., were discussed in each paper.

10 Water Pollution Control Ordinance, Air Pollution Control Ordinance, Noise Abatement Ordinance, Waste Disposal Ordinance, Environmental Impact Ordinance.

11 The consultants' initial reasons given in para.1.2 of Consultation Document No.1 were later acknowledged by them as being no longer applicable in para.1.2 of their Final Report.

12 Although the unit did not attain the status of a separate Government department, it was intended to be established within the Environmental Branch (para.2.2.1, Consultative Document No.1.).

13 Waste Disposal Ordinance (Cap.354), Water Pollution Control Ordinance (Cap.358), Air Pollution Control Ordinance (Cap.311).

14 Noise Control Bill (published in Special Supplement No.5 to Gazette No.11 1987).

15 The Environmental Impact Ordinance was recommended as the fifth statute but see subsequent comments of Environmental Resources Ltd., in paper titled "Preliminary note on changes in ERL proposals consequent on the Hong Kong decision not to pass new planning legislation".

16 of 1980.

17 LN. 112/80.

18 LN. 119/85.

19 Regulations prescribing the various application forms required for licences have yet to be passed.

20 The term "waste" is defined widely in section 2 of the Waste Disposal Ordinance as meaning "any substance of article which [has been] abandoned".

21 No waste disposal plan (or draft) has yet been prepared.

22 The Collection Authority in the Urban Council area is the Urban Council and in the Regional Council area is both the Regional Council and the Director of Agriculture and Fisheries.

23 There are exceptions to the prohibition against disposal. The disposal of waste into the atmosphere and water is governed by the Air Pollution Control Ordinance and Water Pollution Control Ordinance.

24 41 of 1980.

25 LN. 87/81.

26 The regulations passed in 1986 (LN 149/86), came into operation on April 1 1987. See L.N. 90/87.

27 The term "Waters of Hong Kong" is widely defined in section 2.

28 The Tolo Harbour and Channel Water Control Zone is the only zone to have been designated by the Governor in Council. See L.N. 58/82.

29 The objectives established for the Tolo Harbour and Channel Zone include ten separate criteria e.g. aesthetic appearance, bacteria levels, minimum levels of dissolved oxygen etc. See L.N. 232/82.

30 There are two separate Authorities recognised by the Ordinance - one being appointable by the Governor in Council, the other being designated by the Ordinance. In both instances the Director of Environmental Protection has been made the Authority.

31 Section 6(3) Water Pollution Control Ordinance.

32 7 of 1983 and L.N. 303/83.

33 Draft Air Pollution Control (Specified Processes) Regulations have been recently published for public comment. (Special Supplement No. 15, 1987)

33a The Ordinance does not apply to any air pollutant emitted from furnaces on engines which are used to drive ships, motor vehicles, railway engines or aircraft. (s.3) The Governor in Council may, however, specify the types of fuel which can be used to propel any of the above (s.43(1)(p)).

34 The Air Pollution Control Ordinance (First Schedule) lists 23 different categories of industries which are classified as "specified" e.g., Incinerator Works, Cement Works, etc.

35 Section 2 of the Ordinance defines an air pollutant nuisance as an emission which is either prejudicial to health, causes a nuisance to the inhabitants of a neighbourhood or imperils the safety of air craft.

36 The term "noise" is not defined in the Bill.

37 The Bill specifies six different kinds of noise-creating activities which are capable of constituting an offence at any time e.g. air- conditioning noise, noise from musical instruments, and appliances etc.

38 The Holidays Ordinance (Cap.149) defines a general holiday as any day on which all banks, educational establishments, public offices and Government departments are closed. (section 2)

39 Noise from other places such as sports grounds, educational institutions, places of public entertainment would also be included within this third category.

40 Clause 13 makes clear that such products will need to be identified by regulations.

41 For the purpose of brevity the terms "control legislation", "pollution control legislation" and "specialised legislation", (or any combination), refer collectively to the three Water, Waste and Air Ordinances, and where appropriate to the Noise Control Bill.

42 Once the appropriate notifications have been given by an existing discharger, an exemption is conferred as of right under the control legislation - though it can be varied or even forfeited in certain circumstances.

43 The water and air quality objectives, the waste disposal plan and the technical memoranda, are all examples of such statements.

44 Only one Appeal Board under the Air Pollution Control Ordinance has been appointed so far.

45 A person dissatisfied with a decision of an Appeal Board might however be able to overturn any Board's decision by seeking an order for judicial review.

46 There are some imprisonable offences, but they relate to the disclosure of confidential information.

47 See sections 10 and 11 of the Water Pollution Control Ordinance and the Waste Disposal Ordinance respectively.

48 The Ordinances and the Bill all recognise a number of different defences. These include the sanctioning of lawful authority, that the offence was caused during an emergency, an unforeseeable failure of equipment etc.

49 This is the case under the Water Pollution Control Ordinance and the Waste Disposal Ordinance.

50 The Committee, appointed by the Governor, (see S.47A Interpretation and General Clauses Ordinance (Cap.1) for authority) has two main functions;
(a) To familiarise themselves with the state of the environment.
(b) To advise the Government on the appropriate steps to be taken to achieve a controlled environment.

51 The term "Crown" has different meanings for different occasions. Within the context of Hong Kong it usually refers to the representative of the Queen - the Hong Kong Government.

52 This old common law principle has now been codified by virtue of s.66 Interpretation and General Clauses Ordinance. (Cap.1)

53 See second reading of Waste Disposal Bill 18 July 1979, per the Secretary for the Environment - Official Proceedings of the Legislative Council.

54 Environment Hong Kong 1985, Environmental Protection Agency publication.

55 For example, The Dumping at Sea Act 1974 (Overseas Territories) Order 1975.

56 *Lam Yuk Fong & Another v Attorney General & Another*. Unreported High Court Action No. 11492/83 [1985].

57 See General Secretariat General Circular No. 7/86 for details.

58 The Director of Environmental Protection became the Authority under the Waste, Water and Air Control Ordinances. There were many other changes, for example he assumed the Director of Engineering Development's responsibility for granting discharge consents under Crown lease conditions.

59 For example the Urban Council, Regional Council and the Director of Agriculture and Fisheries have all been designated the Collection Authority under the Waste Disposal Ordinance.

60 The ERL consultants initially envisaged an independent department to act as a central control authority. (See Stage I Report, paras. 9.29 - 9.34), but by the time the Final Report was submitted, a more modest unit was recommended.

61 Details for most of this legislation can be found in the Environmental Protection Agency's *Environmental Protection in Hong Kong 1983-84*.

62 The four are as follows:
The Water Pollution Control Ordinance

The Water Pollution Control (General) Regulations 1986
Water Pollution ontrol (Tolo Harbour and Channel Water Control Zone) Order 1982
Dumping at Sea Act 1974 (Overseas Territories) Order 1975

63 There are other ancillary statutory controls which regulate these other sources of atmospheric pollution. See: Road Traffic (Construction and Maintenance of Vehicles) Regulations 1983.

64 There are similar examples to be observed in the case of both water and waste control.

65 See generally sections 8 & 9 of the Ordinance.

66 See section 15(3)(a) & (b).

67 This statement must be qualified in the case of certain specified processes and where the details, required to be supplied to support an exemption, have not been complied with.

68 For example in the current financial year the Environmental Protection Department's proposed budget has been increased to $82,643,000 (from $24,176,000 in 1986-87).

69 This view is partly supported by the increased numbers of environmental-related questions being asked by both appointed and elected Legislative Council members.

70 See Water Pollution Control Ordinance (section 3), Waste Disposal Ordinance (section 30), Air Pollution Control Ordinance (section 5), and the Noise Control Bill (clause 4).

71 The Technical Memoranda amount to 38 pages in total.

72 For instance there are 13 separate, specified steps to be taken when a construction noise permit (other than piling), is being processed.

73 Only one code of practice, relating to the Disposal of Asbestos, has been published.

74 The extent to which the pollution control Ordinances or the Environmental Protection Department has statutory authority to intervene to prevent the dangers associated with asbestos in buildings may be open to some doubt.

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Part Two

Air Pollution and Radiation in Hong Kong

Impact Assessment of Major Air Pollution Sources in Hong Kong

Y.S. Fung

Introduction

Over the past ten years Hong Kong has experienced a large influx of immigrants from China and South East Asia. Coupled with the natural increase in the existing population, the population grew from 3,948,179 in 1971 to 5,495,500 in 1986 (Reference 1). Although considerable areas had been reclaimed from the sea over the years to obtain developable land, in the ten years from the census of 1971 to that of 1981, the population density was still found to have increased from 3750 to 4760 per square kilometre (Reference 2).

In addition, the distribution of the population is highly uneven. Most of the population has been crowded into the established urban area around Victoria Harbour, comprising Hong Kong Island, Kowloon and New Kowloon. In 1981, the density in this area was 29,000 persons per square kilometre, while the corresponding figure for the New Territories was only 1400 (Reference 2). Therefore, a large scale resettlement of the population by building New towns in less populated areas in the New Territories was and still is needed to reduce over-population and provide better facilities to improve the living environment.

In parallel with the rapid increase in population, Hong Kong also experienced a rapid growth in the economy. Over the past 30 years this was at an average rate of 8 to 9 per cent per annum, with only a brief break during the period of uncertainty during the Sino-British talks on the future of Hong Kong. Despite the population growth, the real level of income per head trebled during this time. The increase in population and the accumulation of wealth by the population created a big market for property. It is a fact that the private sector produced a greater number of flats during the last ten years than public housing schemes (Reference 3). However, there is a distinct difference between public and private housing developments.

Public housing development is mostly the building of new towns or large housing estates. and the New Towns are in the New Territories, mostly in areas with little previous development. So planning of a New Town can incorporate elements for controlling and protecting its environment. However, most of the high-rise buildings built by the private sector are by way of redevelopment of the conurbation (Reference 3), where the developer has little control of the environment. As a result, undesirable intermixing of the residential and industrial areas has occurred, so that an old low-rise factory comes to be surrounded by newly-built high-rise residential blocks with the unpleasant consequence of having a stack outside one's window! This type of problem often occurs in old industrial areas like Kwun Tong, where severe air pollution problems have occurred.

In order to protect the public against uncontrolled emission of chemicals and particulates and to prevent further deterioration of the air quality, Air Pollution Control Regulations have been introduced, specifying air control zones and air quality objectives. Also licence controls have been introduced for 23 different industrial processes. However, before realistic control levels can be set, one needs to know the existing levels of emission. Therefore a survey was started in co-operation with the Air Pollution Control Division of the Labour Department and continued with the same staff when they became a Group in the Environmental Protection Department, formed in 1986.

This survey covered the levels of emission of particulates, organic gases and vapours from trades selected from among those using the 23 processes at present controlled. Methods for assessing the impact of the emission in the population centres near to major air pollution sources were also investigated, with the aim of finding a simple, rapid and realistic method for assessing the environmental impact under local conditions.

Survey on Levels of Emission from Major Air Pollution Sources

Major sources of air pollution may be either mobile or stationary. This paper concentrates on emissions from stationary sources, which are already under statutory control. Because Hong Kong has mainly light industries with low energy content (References 4 and 5), the emission of gaseous pollutants is mostly a local problem except for a few large establishments. There are only two main types of industry currently giving sizable air pollution here - the electricity power stations and Government's domestic waste incinerators.

To keep pace with demand in the expanding economy, the size of the new power stations has increased rapidly in recent years while, for economic and other reasons, the fuel chosen for them is coal instead of oil, bringing a consequent increase in air pollutants, especially in particulates. The rapid urbanisation of the areas near the power stations and incinerators in recent years leads to concern about the effect of the pollutants on the nearby population. Therefore an environmental impact assessment is needed to determine the extent of the problem.

With small scale industry, which is characteristic of Hong Kong, the pollution problem is due to the proximity of factories to residential areas. The recent increasing use of organic and inorganic chemicals, whether as raw material, as solvent for processing, or in an intermediate in fabrication, leads to the discharge of these chemicals into the environment. The discharge may be in the form of gas, vapour or solid particulates. In order to evaluate the extent of these problems, a survey was started to determine the existing levels of pollution at those industrial processes which come under licence control. The object is to produce a data base for use both in the planning of an environmental control strategy and in subsequent assessment of its impact.

The survey has been conducted in the summer months over several years (Reference 6-14). Several factories in each trade were selected in order to obtain as nearly as possible realistic and representative pollution levels. The major gas, vapour and particulate pollutants emitted by the trade were identified, sampled at the stacks and then analysed in the laboratory using methods established by the US Environmental Protection Agency and other suitable methods. Each site was visited between two and 12 times, depending on the variability of the emission from the trade concerned.

The results on the environment of organic and inorganic compounds from selected trades are shown in Table I. It is clear that, for a given trade, the environment is predominantly either organic or inorganic. The concentrations of the compounds emitted vary greatly in the different trades, even for the same organic vapour, e.g., toluene. The concentration of the chemical compound varies greatly at different times and under different loading of the plant. Therefore, the sampling was done when the factories concerned were running at full load and at least two samplings were performed to check for reproducibility.

The emissions of particulates from selected trades are shown in Table II. Method 5 of the US Environmental Protection Agency was followed in all the sampling, during which time iso-kinetic conditions were maintained in order to obtain representative samples from each stack. The results of the survey (Table II) show that the domestic waste incinerators emitted the highest concentrations of particulates, although one power station gave the largest total amount of particulate due to the sheer volume of gas emitted every day. Other major particulate emitters were the asphalt plant and the cement factory.

However, in terms of total volume of particulates emitted, the power stations and the incinerators clearly stand apart from other sources. Both of the power stations are coal-fired and the difference in dust loading is mainly due to the rates at which fuel is burned. However, the marked difference in results between the two incinerators is mainly due to the fact that one had already been equipped with

Table I

Levels of emission of organic and inorganic vapours and gases in selected trades

Trade	Chemical Compounds emitted	Concentration detected ppm	
Power Station A	SO_2	302	
	H_2SO_4	12	
	NO_x	37	
B	SO_2	302	
	H_2SO_4	5 5	
	NO_x	190	
Metal pickling plant	H_2SO_4	5 1	
	HCl	27	
	NO_x	220	
	SO_2	311	
Metal etching plant	NH_3	277	
Metal re-cycling plant	Toluene	131	
	Benzene	21	
	Total aldehyde & ketone	9 8	
Paint coating factory	Toulene	39	
	Methyl ethyl ketone	9 4	
	xylene	6 4	
Magnetic tape manufacture	Toluene	200	
	Methyl ethyl ketone	180	
Plastic re-cycling plant	Toluene	150	
	Methyl ethyl ketone	14	
Gas Works	n hexane	23	(3)
	propylene	0 26	(3)

Notes
1) Sample taken during summers over three years period
2) Number of visits ranged from 2 to 12 according to trades
3) Results are expressed in ppb i e per 10^9

Table II

Levels of emission of particulates from selected trades

Trade		Particulate concentration at 15°C and 1 atm pressure (mg/m^3)	Particulate emission rate (g/s)
Power stations	A	47 0	1440
	B	33 8	505
Incinerator	A	3030	640
	B	93 6	103
Cement factory		37 9	7 3
Asphalt plant		2300	4 9
Clay factory		377	2 04
Alumin um smelting plant		568	0 632
Ceramic Plant		59 1	0 585
Dye ng factory		258	0 107

Notes
1) Samples of particulates taken during summers over three year period
2) Number of visits ranged from 2 to 11 according to trade

Table III
Effect of wind direction on the chemical composition of the Total Suspended Particulates (TSP)

	Pu	Cu	Fe	Cd
Related wind	0 403	0 0798	6 95	0 00341
Unrelated wind	0 243	0 0458	6 64	0 00348
Ratio	1 66	1 74	1 05	0 980

Notes
1) Concentrations expressed n $\mu g/m^3$ air
2) Samples taken over two months period with 29 samples collected and analysed
3) Wind blowing from ESE to S was taken as related and from other directions unrelated

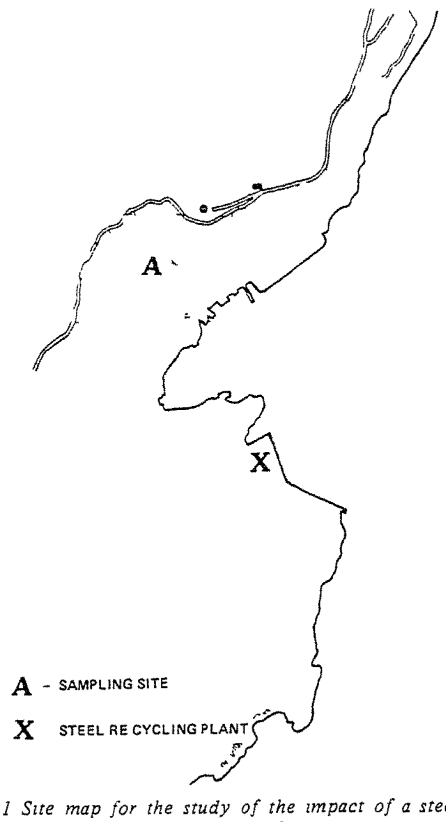

Fig 1 Site map for the study of the impact of a steel re cycling plant on a given sampling site

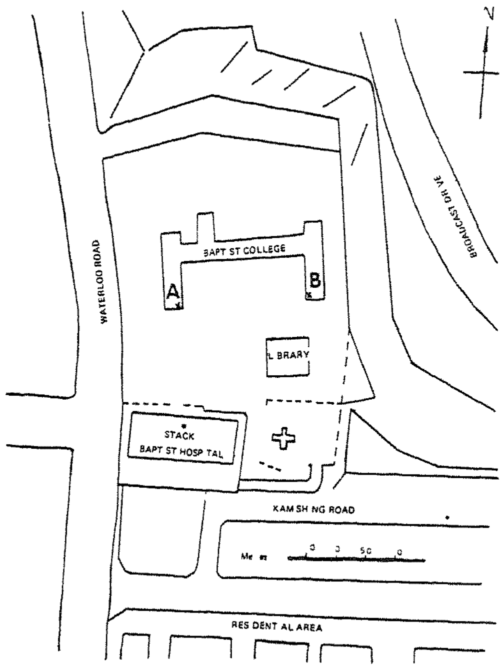

Fig 2 Site map for the studv of the applicabilities of a simple impaction formula

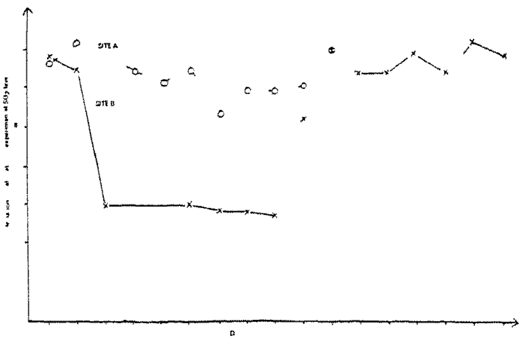

Fig 3 The verification of the simple impaction formula

electrostatic precipitators while the other had not. The considerable reduction in dust emission shows the effectiveness of these precipitators, which are subsequently being installed at the other incinerator.

Impact Assessment of Major Air Pollution Sources

The environmental impact of a major pollution source will depend greatly upon the dispersion of the plume after leaving the stack. Micro-meteorological conditions are important because the occurrence of temperature inversions or certain other climatic conditions can lead to a large reduction in the dispersing power of the atmosphere. For protection of the population near to a major pollution source, the effective concentration of the chemical compounds discharged should be diluted to a safe level before reaching ground level.

To protect the public against potential deterioration of the environment due to the building of any large industrial establishment, such as a power station, large chemical plant or incinerator, an Environmental Impact Assessment (EIA) is now required. This has to be submitted to the Environmental Protection Department (EDP) for approval at the planning stage, prior to construction, and is normally prepared by experts from one of the developed countries outside Hong Kong.

Because the legal requirement for an EIA is primarily for planning approval, the assessment will usually cease once the plant is built. But the pace of development in Hong Kong is very rapid and quite often, once access has become possible via the road built for the plant, the hitherto empty space around it will be occupied by residential blocks within a few years. There are plenty of such cases, examples being by Ap Lei Chau power station and on Tsing Yi Island. Therefore, the process of environmental assessment ought to continue beyond the planning stage, especially where rapid urbanisation occurs around a major source of air pollution.

Because there are many cases of such undesirable intermixing of residential and industrial development in Hong Kong, methods are at present being developed for assessing the impact of existing prominent air pollution sources on the nearby population. One simple and rapid method to demonstrate such impact has been used and is illustrated in one of the projects shown in Figure 1. The source in question is a steel re-cycling plant located near the coast. The sampling site is on top of a school in a valley below the road among the local population centre where there are several small factories and a garbage burning site. The aim of the study was to show that the pollutant in question was coming from the suspected source and producing a significant impact on the levels of the pollutant collected at a given site.

The pollutants investigated were the heavy metals in particulates, which are emitted from the steel re-cycling plant. A high volume sampler was used to collect the air particulates on a filter paper which was subsequently analysed after loading to determine the concentration of various metals collected. The results are shown in Table III.

It is clear that when the wind blows in directions from the source to the receptor, the concentrations of lead and copper are much greater than when the wind is in other directions, whereas those for iron and cadmium are more or less unchanged. This indicates that the lead and copper come from a point source while the iron and cadmium in the particulates originate from an area source.

Various meteorological parameters such as wind speed, direction and source emission rate are needed as input for different mathematical models. However, different models require different inputs and the reliability varies depending on the different surrounding environment. Therefore, verification of the model is required, which can be done either by a wind tunnel experiment or directly in the field.

The topography of Hong Kong is complicated by the concentration of high rise buildings; also, local wind data, especially in three dimensions, is often not available. So it was decided to test the applicability in Hong Kong of a simple mathematical model developed by the Warren Spring Laboratory (Reference 15) in which the following assumptions are made:

1. a steady wind;
2. the plume diverges within a cone of total angle 24°;
3. the concentration of pollutants is uniform across any cross-section through the plume;
4. the pollutant is emitted by an isolated chimney.

The test site shown in Figure 2 has been selected for the following reasons:

(a) no other chimney is near; so the one at Baptist Hospital will be the major source of SO_2 and can be considered to meet the assumption of an isolated chimney;
(b) Baptist College sits on top of a hill at a distance from the main road; so the contribution of SO_2 from traffic will be minimal;
(c) both the source of SO_2 and the sampling sites are at quite a height above ground level so little interference by SO_2 from road level is expected;
(d) there are no tall structures around the site to form reflected sources of SO_2.

Two sampling stations, A and B, were selected, of which Station A is slightly closer to the chimney than B. Both are at a height which can be within the cone angle assumed in the model and no other structures nearby can interfere with the normal dispersion of the plume.

Figure 3 shows the ratio between the results obtained from theoretical calculation and from experimental determinations. In general this ratio is close to 100 per cent, showing a fairly good agreement between the mathematical model and experimental data. However, a marked deviation was observed at Station B during the early part of the project, which may be due to Station B having more variable local wind than A.

The second approach to investigate the environmental impact of air pollutant sources is using the statistical method. Various markers are identified in the sources studied and their corresponding concentrations in the air particulates collected at the receptor site were determined. Then the relative contribution of the given source at a specified receptor site can be calculated. However, in order to increase the reliability of the method, several markers needed to be identified and the relative correlation of their concentrations are calculated. Also a large data set is required to obtain sufficient data to perform the statistical factor analysis. The advantage of this approach is that it is less dependent on the micro-meterological conditions and the terrain near the source and the receptor. However it requires information on the chemical composition of particulates at the source and at the receptors over a long period of time.

A project has been launched using the foregoing approach to investigate the contribution of the air particulates from a coal-fired power station to its environment. The chemical composition of various particulate sources in Hong Kong has been determined and particulates are being collected at five receptor sites with fractionation into different size ranges of particulates before analysis of chemical composition. Up to 20 analyses are being performed on each sample collected. The project will be finished in the summer of 1987 and preliminary data show good correlation amongst various markers identified at the source, especially following the fractionation of the particulates.

Concluding Remarks

The present survey of selected trades under licence control in Hong Kong shows that a large variety of organic and inorganic gases and vapours are emitted. The high cost of land for industrial development and the small scale of most local industries results in the use of multi-storey industrial buildings to house a large variety of different industries. This creates difficulties in controlling pollution, which will have significant impact on the environment, especially at a local scale.The major sources of air pollutants in Hong Kong, especially of particulate emissions, are the incinerators and the power stations.

The fact that the environmental impact assessment of large industrial establishments is at present performed by experts from developed countries has the advantage of passing on the most up-to-date environmental technology. But this brings the disadvantage of only assessing the impact at the planning stage, lacking continuity after the plant is built. Participation of local experts in the EIA process should be encouraged so that the knowledge and information gained may be used afterwards over a longer period for assessing the impact of associated developments. The setting up of an Environmental Group in the Hong Kong Institution of Engineers is an encouraging move to form a much-needed focus where local experts may exchange ideas. This may well lead to their participation on the environmental impact assessment of future major developments in Hong Kong.

Out of the two approaches under study to assess the environmental impact of major air pollutant sources in Hong Kong, the statistical approach seems to offer the better method to be applied locally due to the occurrence of complex terrain around concentrations of high rise buildings and the lack of comprehensive local wind data at most sites. Although assessments are at present done within the Territory of Hong Kong, the rapid industrialisation in the Special Economic Zone to the north should lead to future assessment on a regional basis, in response to the well known dictum in air pollution - "air knows no boundaries"!

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Research Findings on Traffic-related Air Pollution near the entrance of the Hong Kong Cross Harbour Tunnel

L.Y. Chan, H.M. Chiu and Walter A. Palmer

Introduction

Vehicle emissions account for a significant portion of the atmospheric pollution in urban environments. These emissions contain toxic components, constitute an odour and irritant nuisance, and contribute to soiling and damage to property. For these reasons, the rate of vehicle pollutant emissions, expressed as the concentrations of pollutants at the roadside as a function of the traffic flow volume, is an important parameter both for assessing the potential risk to public health posed by present rates of emission, and as a basis for urban planning and air quality policy development.

Vehicle emission characteristics may be expected to vary significantly among urban areas in different regions of the world and at differing levels of economic development due to the great differences in vehicle fleet characteristics (especially vehicle-type composition, general vehicle age and level of maintenance). The study described in this report was undertaken by the H.K. Polytechnic Centre of Environmental Studies (CES) for the purpose of developing data regarding vehicle pollutant emission characteristics specific to Hong Kong.

For a period of over two years (from late 1984 to 1986) CES has monitored the concentration of pollutants at a site adjacent to one of the most heavily trafficked roads in the Territory; Hong Chong Road at a point approximately 600 m from the Kowloon end of the Cross Harbour Tunnel (see Figure1). Analytes monitored include the major pollutants associated with vehicle emissions; sulphur dioxide (SO_2), nitric oxide (NO), oxides of nitrogen (NOx), carbon monoxide (CO), methane (CH_4), non-methane hydrocarbons (NMHC), and total particulates. Particulate matter collected was subsequently analysed for lead, zince, and iron content. Climatic parameters were also recorded throughout the monitoring program. A feature of this monitoring program which makes the generated data especially useful is the proximity of the monitoring site to the Cross Harbour Tunnel toll plaza. Records from the Cross Harbour Tunnel Company of vehicles passing through this plaza allow a direct comparison of atmospheric pollutant concentrations with traffic composition and flow rates.

This report presents an initial analysis of some of the data developed, representing the results of monitoring during 1985. Analytes discussed are NO, NOx, CO, NMHC and CH_4. The average concentration levels of these pollutants and their correlation with traffic patterns are presented.

Methods of Measurement

In this study, air pollutants and meteorological parameters were measured over an average of 20 days per month of data collection for most pollutants. The air was sampled through inlets 1.8 m above the ground and approximately 0.5m back from the kerbside.

Levels of NO, NO_2 and NOx were measured using a Thermo-Electron Model 14 B/E chemiluminescent NOx analyser. SO_2 levels were also measured with Thermo-Electron Model 43 pulsed flourescent SO_2 analyser. These instruments were calibrated using a Monitor Labs calibrator Model 8550. A Horiba ambient hydrocarbon monitor model APHA-300E utilising a dual-channel, dual hydrogen flame ionisation detector analyser was use to measure non-methane, methane and total hydro-carbon. The CO data was obtained from a cross-flow-modulated non-dispersive infra-red analyser, model APMA-300E manufactured by Horiba. Total suspended particulates were sampled using a G.M.W. model GMWL-2000H high volume sampler, while particulate size distribution was monitored with a Sierra-Anderson model 218K ambient cascade impactor. Airborne lead, zinc and iron were analysed with a Perkin-Elmer model 3030 atomic adsorption spectrophotometer. Wind speed and wind direction were measured by a climatronics WM-III system.

The monitoring and sampling instruments were housed in an air-conditioned environment. Air sampling frequency was set continuously at two-minute intervals, 24 hours per day. A 20-channel Microdata M1680 data logger was used to store up to three weeks of data. The data was later transferred to a microcomputer with a 30 mega-byte hard disk for analysis.

Hourly flow of one-way and two-way traffic through the Cross Harbour Tunnel was supplied by that Company. Some manual traffic counts were also carried out for selected days.

Statistical Analysis of Data

Preliminary statistical analysis has been carried out for the data collected during 1985, including univariate analysis and correlation of NO, NOx, CO, CH_4, NHMC concentrations with traffic volume. Winter data for SO_2 concentration

Fig. 1 Map of sampling location

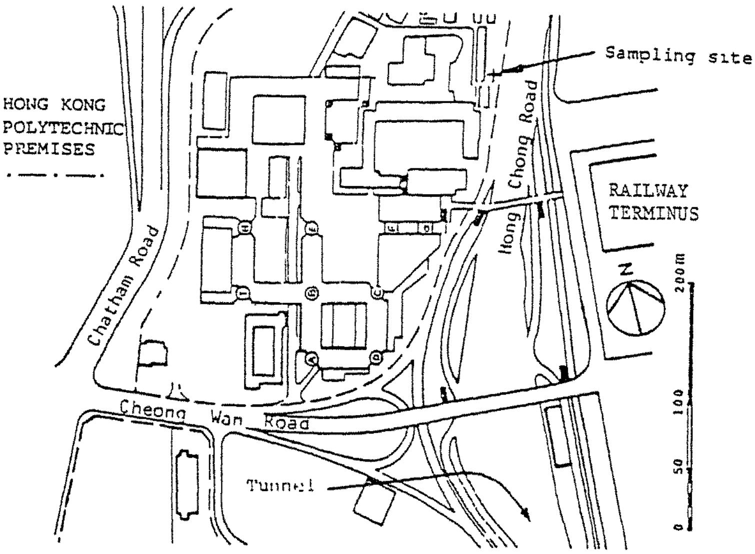

Fig.2 **Winter Time Average Diurnal Plot**

Full range: NO_X-1ppm, CO-7ppm, NMHC-2ppm, CH_4-2.6ppm, Traffic-7000 Vehicles

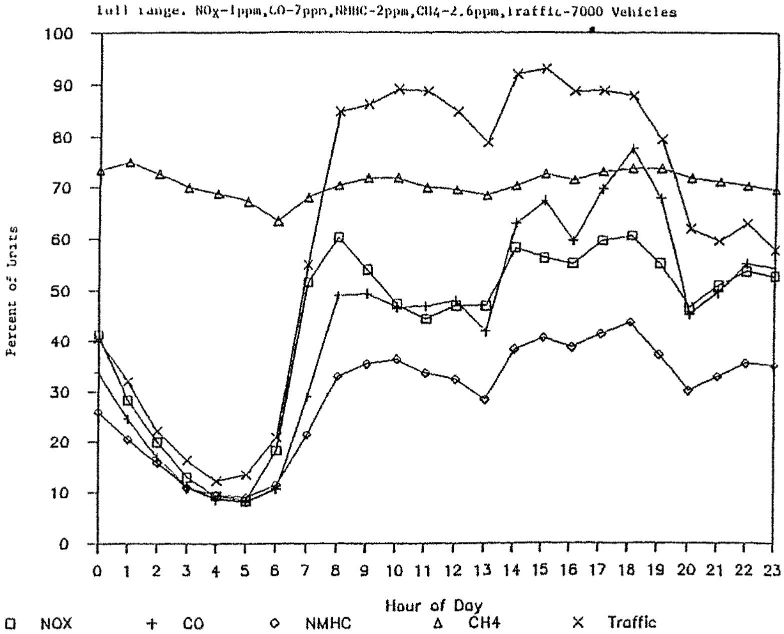

Fig.3

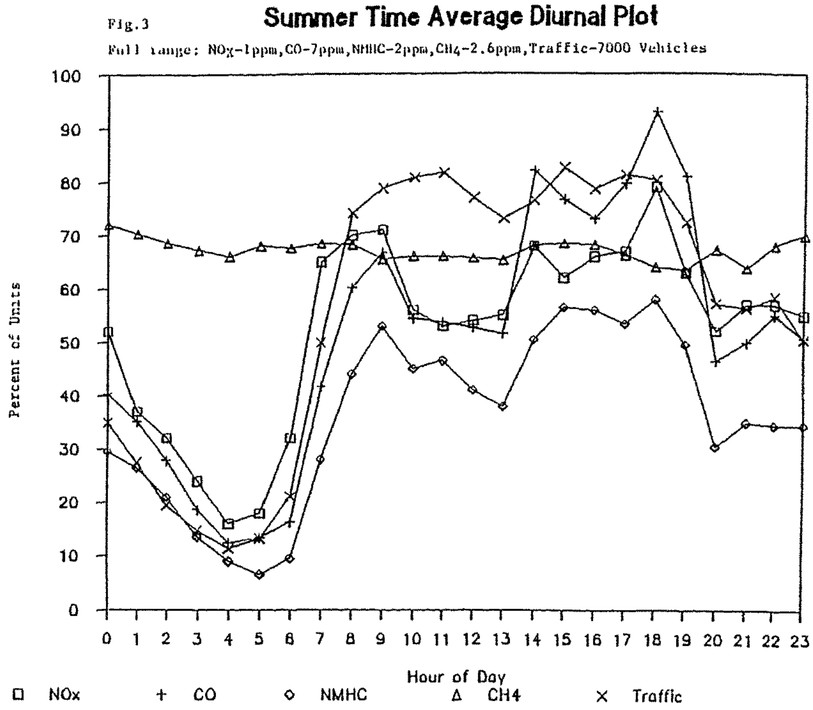
Summer Time Average Diurnal Plot
Full range: NOx-1ppm,CO-7ppm,NMHC-2ppm,CH4-2.6ppm,Traffic-7000 Vehicles
Percent of Units
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of Day
NOx
CO
NMHC
CH4
Traffic

Table 1 Average Concentrations for Each Hour, Study-Wide

Hour	0 N=110	1 N=110	2 N=110	3 N=117	4 N=117	5 N=118	6 N=116	7 N=116	8 N=116	9 N=114	10 N=112	11 N=113
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
NO	0.265 (0.140)	0.179 (0.116)	0.139 (0.094)	0.100 (0.081)	0.078 (0.066)	0.099 (0.105)	0.209 (0.137)	0.419 (0.160)	0.462 (0.151)	0.444 (0.155)	0.400 (0.145)	0.395 (0.126)
NOx	0.328 (0.164)	0.232 (0.123)	0.186 (0.101)	0.148 (0.087)	0.119 (0.070)	0.146 (0.116)	0.266 (0.149)	0.486 (0.159)	0.536 (0.157)	0.521 (0.171)	0.483 (0.155)	0.471 (0.137)
CO	2.35 (1.30)	1.79 (1.00)	1.36 (0.825)	1.00 0.632	0.706 (0.474)	0.879 (0.549)	1.25 (1.01)	2.38 (1.32)	3.52 (1.46)	3.82 (1.61)	3.82 (1.52)	3.91 (1.57)
NMHC	0.497 (0.379)	0.400 (0.322)	0.311 (0.236)	0.237 (0.195)	0.189 (0.155)	0.209 (0.186)	0.288 (0.252)	0.500 (0.307)	0.746 (0.374)	0.877 (0.460)	0.953 (0.734)	0.931 (0.507)
CH_4	1.84 (0.411)	1.83 (0.420)	1.78 (0.329)	1.76 (0.230)	1.73 (0.293)	1.74 (0.351)	1.75 (0.36)	1.78 (0.377)	1.79 (0.338)	1.79 (0.337)	1.78 (0.267)	1.77 (0.253)

Hour	12 N=116	13 N=116	14 N=115	15 N=117	16 N=116	17 N=118	18 N=119	19 N=119	20 N=119	21 N=118	22 N=118	23 N=118
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
NO	0.410 (0.115)	0.405 (0.123)	0.488 (0.165)	0.455 (0.169)	0.466 (0.163)	0.497 (0.175)	0.521 (0.222)	0.457 (0.183)	0.382 (0.154)	0.403 (0.173)	0.389 (0.177)	0.361 (0.181)
NOx	0.484 (0.119)	0.485 (0.128)	0.575 (0.173)	0.537 (0.172)	0.543 (0.173)	0.577 (0.178)	0.600 (0.230)	0.534 (0.193)	0.450 (0.161)	0.470 (0.183)	0.453 (0.183)	0.433 (0.197)
CO	3.97 (1.66)	3.90 (2.00)	5.59 (2.48)	5.23 (2.09)	4.71 (2.16)	5.32 (2.40)	5.76 (2.89)	4.84 (2.23)	3.41 (1.61)	3.65 (1.80)	3.74 (1.77)	3.44 (1.77)
NMHC	0.872 (0.408)	0.818 (0.412)	1.07 (0.519)	1.07 (0.626)	1.01 (0.559)	1.05 (0.578)	1.08 (0.630)	0.914 (0.555)	0.694 (0.405)	0.726 (0.437)	0.717 (0.436)	0.678 (0.440)
CH_4	1.76 (0.227)	1.75 (0.222)	1.78 (0.309)	1.81 (0.338)	1.80 (0.315)	1.80 (0.297)	1.81 (0.354)	1.82 (0.428)	1.82 (0.392)	1.81 (0.330)	1.84 (0.376)	1.89 (0.649)

Table 2 Seasonal Average Concentrations
(average of 1-hour means)

	Summer N=1371				Winter N=1430				Overall N=2801			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
NO	0.395	0.198	1.29	<DL	0.309	0.198	1.03	<DL	0.351	0.202	1.29	<DL
NOx	0.467	0.212	1.33	0.04	0.373	0.210	1.16	0.02	0.420	0.217	1.33	0.02
CO	3.97	2.50	16.43	0.02	2.75	1.86	11.29	0.12	3.35	2.28	16.43	0.02
NMHC	0.825	0.571	7.77	<DL	0.581	0.461	2.28	<DL	0.700	0.532	7.77	<DL
CH_4	1.75	0.399	7.53	0.01	1.83	0.303	4.46	0.73	1.79	0.356	7.53	0.01

Table 3 Summer Correlation Coefficients of NO, NOx, CO, TNM and Traffic

	NO	NOx	CO	TNM	Traffic
NO	1.000	0.931	0.767	0.641	0.558
NOx	0.931	1.000	0.792	0.635	0.539
CO	0.767	0.792	1.000	0.632	0.593
NMHC	0.641	0.635	0.632	1.000	0.559

Table 4 Winter Correlation Coefficients of NO, NOx, CO, TNM and Traffic

	SO_2	NO	NOx	CO	TNM	Traffic
SO_2	1.000	0.698	0.698	0.767	0.835	0.491
NO	0.698	1.000	0.993	0.837	0.835	0.517
NOx	0.698	0.993	1.000	0.832	0.834	0.525
CO	0.767	0.837	0.832	1.000	0.926	0.610
NMHC	0.835	0.835	0.834	0.926	1.000	0.608

levels (available only from October 1985 onwards) are also included in these analyses.

The hourly averaged concentration level for NO, NOx, CO, NHMC and CH_4 in ppm for the period of study is summarised in Table I together with the standard deviation; while the seasonal hourly averaged concentration levels in ppm together with standard deviation, and maximum and minimum concentrations, are presented in Table II.

The traffic flows used are the total two-way traffic using the tunnel. These traffic data (approximately one week of data per month) were used in the analysis and interpretation of the pollution data. It has to be pointed out that because the traffic data supplied in the week of June happened to coincide with the typhoon period with considerably lessened traffic flow, the number of automobiles in the summer diurnal plot for traffic has been considerably reduced. Figures 2 & 3 show the profiles of the averaged diurnal variations for CH_4, NMHC, NOx, CO and traffic flow volume during the winter and summer periods (expressed as a percentage of the indicated full range). The correlation between these atmospheric pollutants as well as SO_2 for the winter months with traffic and each other can be found in Tables III and IV.

Discussion and Conclusions

The pollution levels recorded at the monitoring site reveal that the mean concentration for NO, NOx, CO and NMHC are higher in summer than in winter (Table I and Table II). It has been shown (Reference 1) that non-methane hydrocarbon, nitric oxide, oxides of nitrogen and carbon dioxide generally follow a lognormal distribution during the day-time busy traffic period, whilst slight deviation from the lognormal distribution are observed during the night-time light traffic periods.

In general, the pollutant levels correlated with traffic flow (see Table III and Table IV) but the coefficients of correlation were relatively low:

	NO	NOx	CO	NHMC
Summer months	0.558	0.539	0.593	0.559
Winter months	0.517	0.525	0.610	0.608

These indicate that the roadside concentration levels of the monitored pollutants are not only influenced by traffic flow volume but also are subject to influence from other parameters, possibly including traffic flow patterns, exhaust emission rates at different traffic speeds, the amount of time vehicles stand idling when queuing in front of the toll booth, wind speed, wind direction or solar radiation (see Figures 2 & 3). It is found that the correlation between CO and NMHC with traffic is better than between NO and NOx with traffic. SO_2 shows the least correlation with the traffic as indicated by the value obtained for the winter months.

The correlation among the concentrations of NO, NOx, CO, and NMHC themselves is also presented in Table III and IV. The results indicated that these pollutant concentrations correlate well with each other in some cases, suggesting that these pollutants are from a common source. Correlations between pollutants are better during the winter months than in summer months.

The interrelationship between traffic flow patterns, traffic volume, vehicle type, meteorology and atmospheric pollutant concentrations are clearly somewhat complex, and further analysis will be performed in an attempt to define these relationships more clearly. The data presented herein are preliminary, but indicate some interesting relationships between these parameters.

Reference

1. Chan, L.Y. and K.S. Lam, "Methane, Non-methane Hydrocarbon, Carbon Monoxide and Oxides of Nitrogen Concentration in Roadside Ambient Air". *POLMET 85*, edited by M.W.H. Chan *et al*, Elsevier Applied Science Publishers, pp.184-189, 1985.

Gamma Radiations from Soil in Hong Kong

Lau Shun Yin, Leung Kon Chong, and Tang Chin Ho

Abstract

The specific activities of the γ-emitters in soil have been determined with a high resolution γ-ray spectrometer. The results of 37 soil samples at different locations in Hong Kong are presented in this paper. The dominant radionuclide is K^{40}, which accounts for 50% of the total γ-activity in the soil samples. The other 50% is shared by nuclides in the U^{238} and Th^{232} series. The specific activity of Cs^{137} contamination ranges from about 16 Bq/Kg down to less than 1 Bq/Kg. The average concentration of this contaminant is around 3 Bq/Kg in surface soil. This could be useful in serving as a baseline for radiation monitoring in relation to the nuclear plant near Hong Kong.

Introduction

Concern about exposure to ionizing radiations from external environmental sources has been noted by many workers. The Environmental Radiation Group in the Department of Applied Science, Hong Kong Polytechnic, started measurements of this kind in 1983. The first investigation carried out was on the natural dosimetry of γ-radiation in Hong Kong, the results of which were reported by Lau, *et al.* (1985). The average absorbed dose rate is 70.7 m rad/y for γ-ray with energy above 100 keV. This result is in consistant with that reported by Chuang, *et al.* (1970) fifteen years ago.

It is generally recognized that in spite of the safety measures incorporated in the design of a nuclear power plant, slight contamination in soil, atmosphere and biosphere with man-made nuclei in the surrounding area are inevitable during its normal operation. In order to determine the increase in radiation level due to the operation of the nuclear plant at Daya Bay, not only the background radiation level due to total radiation should be known, but also the details of the radionuclides involved should be determined. Gamma spectral analysis offers the quickest and simplest yet very powerful means for contamination monitoring.

Of the γ-emitters present in the environment, the majority are daughters of U^{238} and Th^{232} nuclides which are distributed by natural geological and geochemical processes. These radionuclides are shown in Figure 1 and 2 for reference (Gusev, *et al.* 1979). In addition to these primordial origin radionuclides, there are other non-related naturally occuring sources (e.g. K^{40}) and small quantities of fission-product residues (e.g. Cs^{137}) from atmospheric nuclear weapons tests and also nuclear plants, no matter normal or abnormal releases. Local variations in the distribution and availability of these γ-emitters are complicated but interesting.

The purpose of this study is therefore to study the nature and distribution of the radionuclides in our local environment, to contribute to establishing the 'baseline' concentration of γ-emitters throughout Hong Kong territory.

Samples and Methods

Thirty-seven soil samples representing the major soil types (Grant, 1962) were collected from various sites in Hong Kong. The exact locations are shown in Figure 3. Samplings were made on exposed ground not likely to have been disturbed for over one year. The soil samples were collected from the surface layer to a depth of around 20 cm. It was quite difficult to dig into a greater depth as some of the locations are rich with rock and stones.

The samples were air-dried in an air-conditioned laboratory. About 1.2 Kg of each sample was put into a container similar to a Marinelli beaker to ensure a standard counting geometry. The Marinelli beaker used was not sealed, so that the radon daughter concentrations will reflect more environmental concentrations.

Gamma spectrum of each sample was determined with an EG & G ORTEC high purity "p-type" germanium coaxial detector, model GEM-10175, connected to a 4096 multichannel analyzer. The resolution of the HPGe detector made it possible to resolve a wide spectrum of γ-emitters in the soil samples being studied.

The energy calibration was done frequently by using Am^{241} (59.54 keV) and K^{40} (1461 keV). For efficiency calibration, together with self-absorption correction, a sample of granitic soil with high concentration of Bi^{214} radionuclide was measured to determine the relative efficiency of the detecting system at different γ-energies. Although the Bi^{214} concentration was not known, the branching ratios of different γ-emission energies can be found from published data, such as ICRP Publication No. 38 listed in Table 1.

It can be seen that the energy range of Bi^{214} and its short-lived parent Pb^{214} covers the major γ-energies of the other radionuclides of interest. The measured net counts of the energy-peaks in the spectrum of granitic soil sample, together with the given branching ratios, gave a relative efficiency curve. Then, a known

Table I
Branching ratios of different γ-energies emitted from Pb^{214} and Bi^{214} from ICRP Publication No.38

Energy	Branching (%)
295.2	19.2
351.9	37.1
609.3	46.1
934.8	3.16
1120	15.0
1238	5.92
1378	4.02
1730	3.05
1764	15.9
1848	2.12
2204	4.99
2448	1.55

Table II
Performance factor of the detecting system.

radio-nuclide	major energy Ei (keV)	branching ratio (%)	F(Ei) x 10^{-3}
Pb^{214}	351.9	37.1	7.77
Bi^{214}	609.3	46.1	4.44
Ac^{228}	911.1	29.0	2.91
Pb^{212}	238.6	44.6	11.1
Bi^{212}	727.2	11.8	3.68
Tl^{208}	583.1	85.8	4.60
K^{40}	1461	10.7	2.02
Cs^{137}	661.5	85.1	4.12

The estimated errors of performance factors of Pb^{214} and Bi^{214} are within 0.08×10^{-3} and 0.05×10^{-3} respectively.

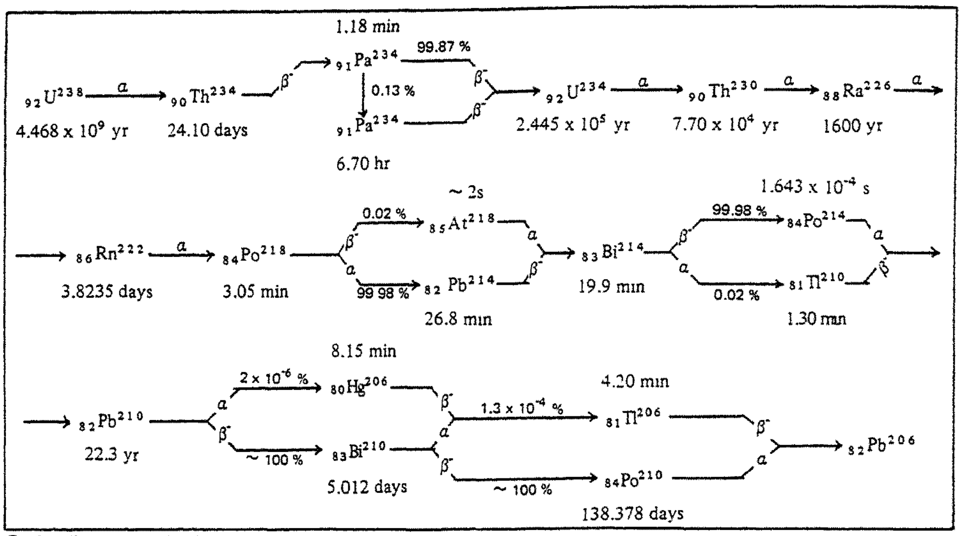

Fig.1 The uranium family

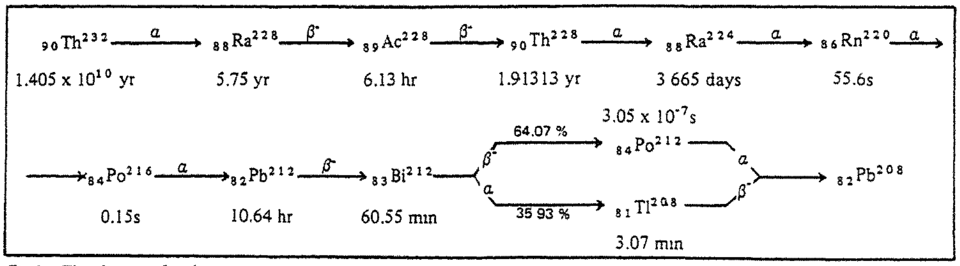

Fig.2 The thorium family

Table III
Concentration of radio-nuclides in 1983 soil samples (Bq/kg)

Locations	Pb^{214}	Bi^{214}	Ac^{228}	Pb^{212}	Bi^{212}	Tl^{208}	K^{40}	Cs^{137}	Total
Tai Tam Reservoir	51.2	48.3	171	203	207	57.1	309	9.3	1055.9
Kwai Chung	52.2	68.7	158	202	221	54.5	58.6	4.9	819.9
Sheung Shui	48.3	42.1	38.0	52.8	87.9	13.6	246	1.7	530.4
Tuen Mun	42.9	36.1	63.5	78.6	121	19.0	436	1.6	798.7
Cheung Chau	40.6	45.6	145	157	242	58.4	785	–	1473.6
Pak Ngau Shek	59.0	54.1	55.9	48.5	93.7	22.5	531	3.9	868.6
Wu Kau Tang	56.5	44 8	45.4	50.7	129	17.7	620	4.9	969.0
Tung Chung	55.5	47.7	71.0	65.0	50.8	23.7	210	4.7	528.4
Kam Tin	61.9	58.8	70.1	68.1	96.8	24.8	696	–	1076.5
Tai Wan Village	45.8	55.7	98.8	84.6	164	33.6	271	–	753.5
Cheung Sha	65.8	46.6	79.8	70.0	113	28.9	274	5.2	683.3
Wong Chuk Wan	49.3	51.4	62.9	54.0	90.6	21.7	250	–	579.9
Yung Shu Wan	110	106	118	88.9	129	35.5	594	3.7	1185.1
Wong Keng Tei	23.3	25.4	50.1	38.0	71.4	10.9	215	–	434.1
Tai Mong Chai	56.5	57.8	116	118	149	49.9	671	–	1218.2
Pok Fu Lam	43.5	46.4	81.7	68.9	96.5	29.1	366	3.1	735.2

Table IV
Concentration of radio-nuclides in 1985 soil samples (Bq/kg)

Locations	Pb^{214}	Bi^{214}	Ac^{228}	Pb^{212}	Bi^{212}	Tl^{208}	K^{40}	Cs^{137}	Total
Stanley Fort	53.7	48.8	121	87.3	76.2	29.6	714	1.5	1132.1
Tai Tam Reservoir	50.0	39.2	141	113	77 3	43.7	362	15.9	872.1
Tai Tam 1	47.7	45.1	168	134	188	48.8	310	–	941.6
Tai Tam 2	49.2	43.3	161	135	116	48.5	322	0.7	875.7
Tai Tam 3	47.7	42.9	158	133	113	44 0	330	–	868.6
Tai Tam 4	47.0	41.1	131	125	137	47 4	344	1.1	873.6
Tai Tam 5	51.8	44.4	154	120	130	45.1	374	1.5	920.8
Chai Wan Cemetery	45.5	37.0	178	136	142	53.3	151	0.4	743.2
Stanley village	53.3	44.0	96.9	77.3	73.3	29.6	851	2.6	1228.0
Shek O	53.7	51 4	141	106	129	39.6	503	1 9	1025.6
Wong Nai Chung	43.7	35.2	132	111	85.5	39.2	555	5.2	1006.8
Victoria Peak	45.5	38.5	184	145	118	50.7	226	1.1	808.8
Aberdeen Country Park	34 0	30.7	88 8	72.5	51.8	25.1	366	3 3	672.2
Chung Hom Kok	52.9	48.1	130	84 4	78 8	35.5	551	–	980.7
Tsam Chuk Wan	34.0	29.6	57.4	37.0	21.8	17.8	447	–	644.6
Tai Lam Chung Res.	81.4	69.9	108	62.5	18.9	24 8	825	1.5	1192.0
Tai Lam Chung Water Bay	81.4	74.7	126	86.6	95.1	10 0	607	3.7	1084.5
Tai Au Mun 1	39.2	36.3	67.0	51.1	31.5	19.2	470	7.4	721.7
Tai Au Mun 2	44.8	41.8	88.1	70.3	77.7	24.4	459	7.4	813.5
Tai Au Mun 3	43.3	38.9	72.2	46.6	31.8	21.5	518	5.6	777.9
Tai Au Mun 4	42.2	35.9	79.6	77.0	80.7	21.8	477	7.8	822.0
average statistical error	3.5%	4 0%	4.1%	13%	40%	3.4%	3.5%	25%	

Table VI
Contribution of the γ-emitters to the total γ-activity

nuclide	percentage
Pb^{214}	5.8 %
Bi^{214}	5.4 %
Ac^{228}	12.3 %
Pb^{212}	10.6 %
Bi^{212}	12.0 %
Tl^{208}	3.7 %
K^{40}	49.8 %
Cs^{137}	0.4 %

Table V
Average specific activity of the γ-emitters (Bq/kg)

γ-emitter	Average (Bq/kg)	Standard Deviation	Range (Bq/kg)
Ac^{228}	108.330	41.737	38.0 – 184
Pb^{212}	93.478	41.342	37.0 – 203
Bi^{212}	106.381	51.503	21.8 – 242
Tl^{208}	32.986	13.781	10.0 – 58.4
Pb^{214}	51.468	14 623	23.3 – 110
Bi^{214}	47.359	14.368	25.4 – 106
K^{40}	440.395	191.690	58.6 – 851
Cs^{137}	3.016	3.358	0.0 – 15.9

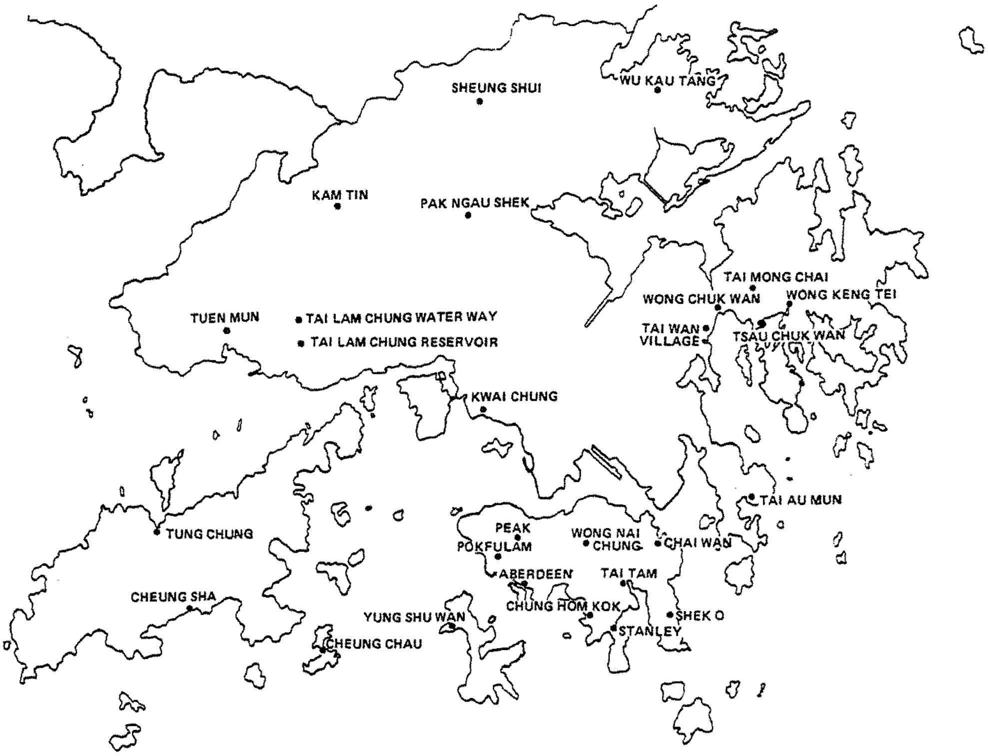

Fig.3 Location of the sampling places

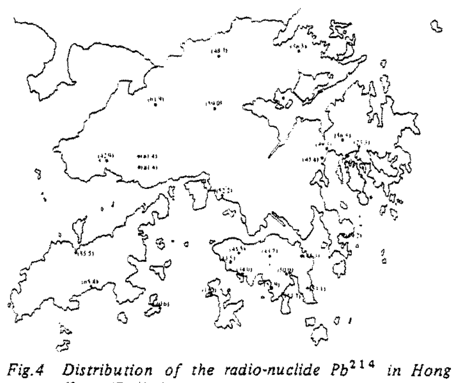

Fig.4 Distribution of the radio-nuclide Pb^{214} in Hong Kong (Bq/kg)

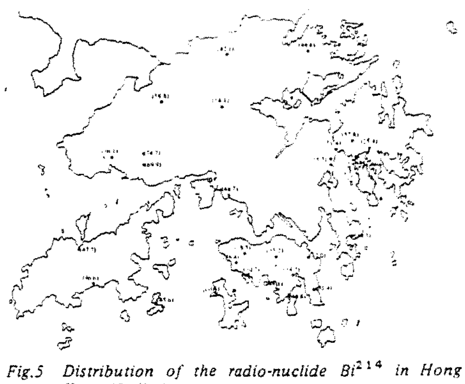

Fig.5 Distribution of the radio-nuclide Bi^{214} in Hong Kong (Bq/kg)

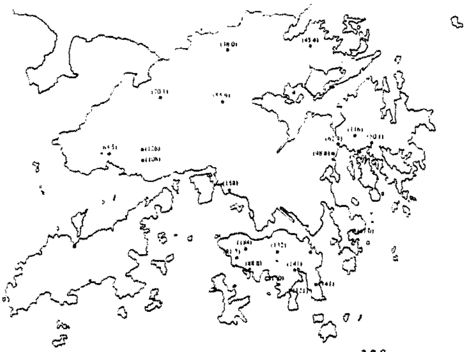

Fig.6 Distribution of the radio-nuclide Ac^{228} in Hong Kong (Bq/kg)

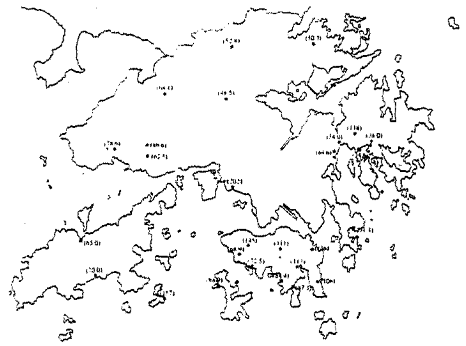

Fig.7 Distribution of the radio-nuclide Pb^{212} in Hong Kong (Bq/kg)

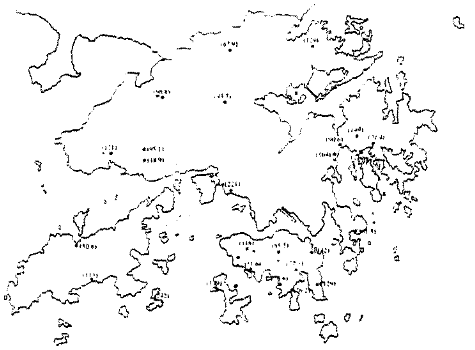

Fig.8 Distribution of the radio-nuclide Bi^{212} in Hong Kong (Bq/kg)

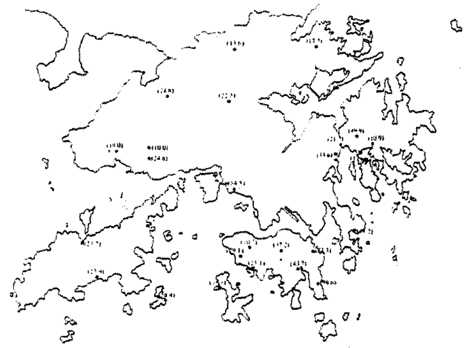

Fig.9 Distribution of the radio-nuclide Tl^{208} in Hong Kong (Bq/kg)

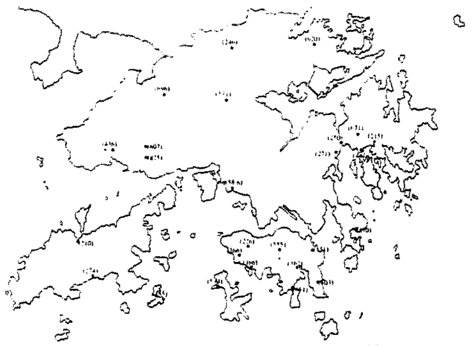

Fig.10 Distribution of the radio-nuclide K^{40} in Hong Kong (Bq/kg)

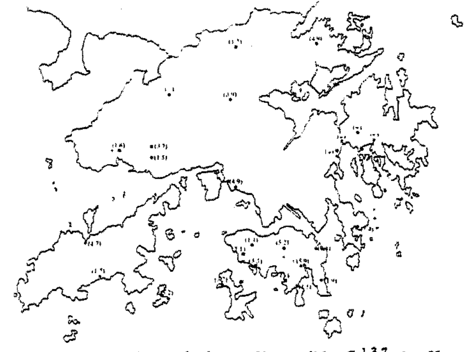

Fig.11 Distribution of the radio-nuclide Cs^{137} in Hong Kong (Bq/kg)

weight of KC1 salt, with an isotope abundance of 0.01181% of K^{40} and specific gamma activity of 3.25 ± 0.07 Bq/g of potassium (Lentz, *et al.*) was mixed into the soil sample. The absolute efficiency at 1461 keV was then determined and the whole relative efficiency curve was calibrated to that point. The efficiency calibration with correction of self-absorption in the soil sample was then completed. The resultant performance factors F(Ei) at the major γ-energies, Ei of each radionuclide interested, are listed in Table 2. The performance factor F(E) is defined as

$$F(Ei) = G \times S(Ei) \times \varepsilon(Ei) \quad \text{(eqn.1)}$$

where:
G is the geometric factor
S(Ei) the self-absorption correction factor, and
ε(Ei) the intrinsic efficiency of the HPGe crystal at this particular energy

The relationship between the measured γ-counts C(E) at energy E, given by the net area of the photo-peak abovethe γ-continuum, and the true activity A of that radionuclide in the soil sample is given by:

$$A(Ei) = \frac{C(Ei)}{t \times F(Ei) \times \eta} \quad \text{background concentration (eqn.2)}$$

where:
t is the measuring life time in units of second and
η is the branching ratio of the γ-energy considered.

Results

The emission from each sample was measured for a period of at least three hours. This gave a minimum detectable level of about 1 Bq/kg. The γ-emitters were identified from the γ-spectra according to their characteristic γ-energies. Except Cs^{137} and K^{40}, all the other γ-rays detected came from members in the U^{238} and Th^{232} series. Cs^{137} was the only man-made isotope observed in the γ-spectra. K^{40} and the isotopes from the two natural series are the major natural terrestrial γ-radiation sources. The measured specific activites of the γ-emitters of two lots of samples taken in 1983 autumn and 1985 summer are listed in Tables III and IV. The statistical counting errors are also listed in Table IV. The distribution of the radio-nuclides are shown in Figures 4 to 11.

The average specific activity of the γ-emitters in Hong Kong soil are presented in Table V.

The average total specific γ-activity in the 37 samples was 884 Bq/kg or 0.884 Bq/g of dried soil. According to Tables III and IV, the total activity spans through a range from 434.1 Bq/kg to 1473.6 Bq/kg.

The percentage contribution of each nuclide to the total γ-activity are listed in Table VI.

Discussion

Only matters concerning environmental impact will be discussed in this paper.

The distribution of the series of radio-nuclides resulting from the decay of U^{238} and Th^{232} depends on complicated geological and chemical processes. Radon occurs as a decay product of U^{238} and Th^{232}; as Rn^{222} and Rn^{220} respectively. Radon exists in gaseous form and is water soluble. The distributions of radon and hence of its daughters are greatly influenced by rain water, wind and the type of soil, as well as by the emanation rate of radon gas from the soil. But basically, the concentration of the daughter nuclides can reflect the content of the U^{238} and Th^{232} in the soil if sufficient samples are carefully chosen from undisturbed sites.

The nuclides Pb^{214} and Bi^{214} are the daughters of U^{238}. From Figures 4 and 5, it can be seen that the specific activities of these two nuclides are more or less the same throughout the Territory if one takes their inherently large deviations into consideration. But, there are three places having definitely higher values which have to be discussed. The samples taken from Tai Lam Chung reservoir and Tai Lam Chung water way are yellow podsolic soil, a decay product of granite. The granite in Hong Kong has a high U^{238} content, about 10 ppm by weight. (The radioactivities in Hong Kong rocks have been studied in the Department of Applied Science, Hong Kong Polytechnic, and the results will be published soon). This could explain the high specific activities of Pb^{214}, which is about 80 Bq/kg, and Bi^{214}, which is about 70 Bq/kg.

The highest activity due to U^{238} daughters is found in Yung Shu Wan with Pb^{214} of 110 Bq/kg and Bi^{214} of 106 Bq/kg, both far above average. The soil type is red loam and should not be extraordinarily high in U^{238} content. Possibly the high Pb^{214} and Bi^{214} activities result from contamination due to human activity. It is suspected that the coal-fired power station near the sample-collecting site may have some effect. It was reported by Coles, *et al* (1978) that the specific activities of Ra^{226} and U^{238} in the fly ash of mass median diameter 2.4 μm are 5.9 pCi/g (218.3 Bq/kg) and 12 pCi/g (444 Bq/kg) respectively. Corbett (1983) pointed out that the possible release of Rn^{222}, the precursor of Pb^{214} and Bi^{214}, from a modern coal-fired power plant is 80 GBq/(GWy). Hence the radioactivity released by coal-fired plants needs more attention and, in particular, it is advisable to become aware of the collective dose received by the population near the power plants.

For the Th^{232} series, the specific activity of Ac^{228} reflects the high content of Th^{232} and its daughter nuclei in soil. From Figure 6, it is interesting to note that the specific activity of Ac^{228} is higher in the southern part of Hong Kong. This can be explained by the igneous rocks distribution in Hong Kong as igneous rocks have high Th^{232} content, around 20 ppm by weight according to our measurements in another project.

Specific activities of Pb^{212} and Bi^{212}, daughters of the much shorter-lived Rn^{220}, bear more geological interest than environmental effects. Their distributions are shown in Figure 7 and Figure 8. It should be pointed out that $T1^{208}$, though at a lower activity, gives the highest γ – dosage of the detected γ – emitters due to its high energy radiation. The overall health effect from these γ-emitters will be presented in another report.

K^{40}, having the highest percentage in the total activity and contributing significantly in plant and food radioactivities, has no significant anomalous distribution as can be seen in Figure 10. The distribution can be explained by the rock distribution in Hong Kong and K-content in the rocks.

The man-made radio-nuclide Cs^{137}, of half-life 30.0 years, is a fallout product of atmospheric nuclear weapon tests and also release (either normal or abnormal) from nuclear power plants. This fission product is an effective indicator of environmental nuclear contamination due to operation of nuclear plants. The average specific activity of the 1983 samples is 2.7 ± 0.7 Bq/kg and of the 1985 samples is $3.3 + 0.8$ Bq/kg. No significant variation in the activity level is detected. It should be mentioned that 17 other soil samples in Hong Kong were collected in autumn 1986 for study in another research project. The average Cs^{137} content of these samples was found to be 2.7 ± 0.7 Bq/kg. It seems that the normal specific activity of Cs^{137} could be around 3 Bq/kg in surface soil. However, it is interesting to point out that Tai Tam Reservoir always has the highest concentration of Cs^{137} among all the sampling sites.

Conclusion

The specific activities of the γ – emitters in Hong Kong soil have been determined and presented in Tables III, IV & V. These data will be useful in serving as a baseline survey for radio-nuclide concentrations in the soils of Hong Kong. The dominant γ – emitter is K^{40}, which accounts for 50 per cent of the total γ-activity in the soil samples. The other 50 per cent is shared by nuclides of the U^{238} and Th^{232} series. The specific activity for the Cs^{137} contamination for the surface soil in Hong Kong ranges from 15.9 Bq/kg down to less than 1 Bq/kg, with an average of around 3 Bq/kg. The present information can be used in establishing what the expected normal range of concentrations of radio-nuclides are in soil, in case these environments are exposed to an external source of radio-nuclide contamination in the future.

Acknowledgment

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Part Three

Waste Disposal and Water Pollution in Hong Kong

Safely Disposing of Hong Kong's Hazardous Wastes

Robert C. Keen and Walter A. Palmer

Abstract

The lack of precise information on elementary issues such as generation rate of dangerous gases and agreed thresholds has often prevented the question of the safe disposal of hazardous wastes being tackled in a truly objective manner in the past[1]. This paper advances a means of providing a numerical assessment of the risks associated with hazardous waste handling and treatment, which might contribute to an informed discussion. Whilst the validity of the relatively simple extrapolation which is suggested will not always stand close scrutiny because of uncertainties over certain cruicial factors such as the efficiency of mixing, or even the precise composition of waste as delivered to the site, the case studies do reveal the extent of the potential for harm in real life situations, and hence underline the need for objectivity.

Introduction

Hong Kong's development as an entrepot for China has meant that it lacks primary industry and has traditionally imported most of the chemical feedstock on which its own industries rely. Hence the control methods which it has evolved to deal with hazardous virgin chemicals and products may not be typical of most other countries which have a more conventional base which includes primary production facilities.

Although there is no specific provision which parallels the UK scrutiny for "major hazard potential" as such, the general planning regulations, when read alongside the provisions relating to fire precautions have evolved to provide a *de facto* position in which the control exercised on new developments is relatively extensive.[2] Because land is in such short supply in Hong Kong, much of it is directly controlled by government and subject to regular inspection by land use specialists (who check on the type of occupancy). It follows that certain precautions (such as those relating to dangerous goods storage in large quantities, for example) do receive a high priority.

Most factories operate in crowded conditions in multi-storey industrial buildings and because of high property prices, little space is given over to waste storage. Collection of industrial waste may even be carried out daily thereby removing the need for extensive storage facilities. Most industrial waste is, of course, non-hazardous and is disposed of at controlled tips in a similar way to household and commercial waste disposal. Those industrial wastes which have to be handled and disposed of separately because of their properties are referred to in Hong Kong as toxic, hazardous and difficult (THD). The proportions of the major types of THD waste is illustrated in Figure 1[3].

A survey carried out in 1981 and 1982 established that the production of THD waste was widespread throughout Hong Kong but that the THD waste generation per employee (average 40 kg/annum) is very low compared with major industrial countries[4]. Because small firms dominate the manufacturing sector, the quantity of THD waste generated by the typical individual firm is relatively low. When aggregated, however, the total volume of THD waste generated in Hong Kong is quite significant. It was estimated that in 1982 THD wastes were generated at the rate of 37,000 tonnes per annum, or roughly 100 tonnes per day. A more recent study[5] estimated that by 1984, this generation rate had increased to 120 tonnes per day (Figure 2).

Few companies make special arrangements for THD waste unless they constitute dangerous goods as defined in the Dangerous Goods Ordinance. Wastes that are liquid are usually flushed into drains; indeed there is clear evidence that in the older industrial areas even storm water drains are being used for such purposes. Solid THD wastes are collected, together with general industrial wastes, by industrial waste contractors and disposed of at controlled tips.

The Environmental Protection Department has listed the following treatment facilities which will be required to handle the wide variety of THD waste produced in Hong Kong[6]:

(i) inorganic waste treatment facilities for neutralisation, oxidation, reduction, precipitation, thickening and sludge dewatering.

(ii) oily waste treatment facilities for separating oil-water mixtures, cracking emulsions and optioanlly reprocessing the recovered oil.

(iii) hazardous waste incineration at high temperature with suitable gas cleaning.

(iv) solvent recovery to recycle high-value solvents and reduce the quantities of halogenated wastes requiring incineration. This allows more efficient operation of the incinerator and simplifies the gas cleaning problems.

These processes are to be provided in a central treatment plant which will serve also as an oily waste reception facility required to fulfill Hong Kong's obligations under the MARPOL international marine pollution convention, which Hong Kong has agreed to implement.

Although waste disposal contractors are part of the scene, and privatisation moves are under consideration, Hong Kong's waste disposal is generally controlled by the Government and carried out either by direct labour or under contract. In view of the specialised expertise required to design, build and operate a THD treatment plant the Government has invited prequalification statements from companies with the necessary expertise and these are currently under evaluation.

Three case studies follow to provide examples of the extent of the hazard which needs to be guarded against.

Case Study 1: Hydrogen Sulphide Fatality[7]

In a widely reported incident in the mid 1970's the driver of a road tanker engaged in discharging toxic waste was fatally gassed on a large UK landfill site.

A, the driver of a tanker, mistakenly discharged 5 tonnes of waste aluminium sulphide liquor into a soakage pit on the landfill site which was reserved for acid wastes. The driver of the next tanker to unload, B, quite properly discharged waste sulphuric acid into the pit; he was subsequently found collapsed in his vehicle cab and was dead on arrival at hospital.

Analysis

Hydrogen sulphide would have been generated when the two wastes met viz:

$$Al_2S_3 + 3H_2SO_4 \rightarrow 3H_2S\ (\uparrow) + 2\ ALSO_4.$$

The weather was overcast with slight rain and a light easterly wind which would have tended to move the generated gas towards B's tanker. The deceased's movements prior to collapsing are not known but his body was found inside the cab with the doors closed and the window nearest the pit slightly open. The vehicle engine was running. The TLV(STEL) short term exposure limit of hydrogen sulphide is 15 ppm (27 mg/m^3). Although the gas has a characteristic, very unpleasant odour with a threshold of less than 1 ppm, olfactory fatigue is rapid and even 10 to 15 ppm is sufficient to inhibit odour sensation completely. Exposure to several hundred to a few thousand ppm results in an increase in frequency of respiration with a decrease in depth of inhalation and after a few breaths, respiration ceases. Collapse either preceeds this stage or immediately follows it.

Mixing of the incompatible substances did not apparently result in any significant threat to the health of driver A. However, the soakage pit was almost empty of acid before the sulphide was mistakenly pumped in. Also, since wastes are inately variable, the residual waste in the soakage pit could have constituted a relatively weak acid incapable of generating a dangerous amount of gas when combined with the uncovenanted load. Furthermore, as driver A left the site immediately and his place was straightaway taken by the deceased's tanker, the time dependent nature of the generation of the gas would work in favour of A and against B, whose load of acid would have accelerated any reaction already taking place. The authors carried out investigations using a simple bench method to investigate this generation rate. The reactants were kept separate in two legs of a reaction vessel until the commencement of the experiment.

Figures obtained from the series of experiments confirm that hydrochloric acid reacting with common sulphides can give a very vigorous reaction. Peak levels approaching 0.5 ml of H_2S per second per ml HCl for liquid/liquid or liquid/solid reactions were recorded with reactants at concentrations which can be encountered in waste disposal routines.

Case Study 2: Hydrogen Sulphide Fatality [(8)]

In the late 1970s a somewhat similar set of circumstances occured in Southern Louisiana, USA. A young tanker driver was fatally poisoned by hydrogen sulphide generated when the waste he was discharging reacted with the contents of an open pit. Subsequently enquiries revealed that the site was one of four being operated illegally and that a permit had been issued for the waste which required disposal in a deep injection well.

Case Study 3: Nitrogen Dioxide Evolution[9]

A demountable tank containing several hundred gallons of waste nitric acid was left at a landfill site which contained an extensive lagoon. An operator was told to connect up pipework so as to drain the acid very slowly over two days into the lagoon. Instead, it was treated as a spent metal finishing acid and discharged in a matter of minutes into a bunded area which already contained a large quantity of such acid. The ensuing reaction resulted in the liberation into the air of a large quantity of nitrogen dioxide. This cloud drifted into the vicinity of adjacent dwellings. Fortunately, no cases of poisoning were reported.

Analysis

Nitric acid HNO_3 is inherently unstable. The reaction:

TABLE I
Toxic gases liberated as a result of
mixing certain chemically incompatible substances (10)

INCOMPATIBLES A	INCOMPATIBLES B	RESULTING TOXIC GAS	TLV (STEL) or TLV (C) ppm
Arsenical Materials	Any reducing agent	Arsine	0.15
Cyanides	Mineral Acids	Hydrogen Cyanide	15
Hypochlorites	Acids	Chlorine	3
Nitrates	Sulphuric Acid	Nitrogen dioxide & Nitrous fumes	5
Copper, brass, many Heavy Metals	Nitric Acid	Nitrogen dioxide & Nitrous fumes	5
Nitrites	Acids	Nitrogen dioxide & Nitrous fumes	5
Phosphorus	Caustic Alkalies or reducing agents	Phosphine	1
Selenides	Reducing Agents	Hydrogen Selenide	0.15
Sulphides	Acids	Hydrogen Sulphide	15

Table II

	Annual Total
1) Number of times incorrect neutralizing material will be drawn from stockpile (0.5% of total)	25(I)
2) Number of consignments arriving which are sufficiently ´off specification´ to give rise to a hazard (0.5% of total)	25
3) Number of significant veracity checks missed or improperly executed (5% of 2)	1.25(II)
4) Number of times that correct operating instructions will be wrongly interpreted	25(III)
5) Number of times that incorrect operating instructions will be utilised	25(IV)

Table III

Parameters for assessing risks to populations beyond site boundaries, resulting from a toxic gas release

Nature of Contaminant Release
Duration (seconds, minutes hours, or days); total mass; steady or fluctuating rate; temperature; height (i.e. through a stack)
Contaminant Properties
Atmospheric decay rate. Relative affinity for adhering to airborne dust particles or dissolution in airborne water droplets; rate of settleout or rainout. Density relative to air. Human toxicity as a function of concentration/exposure duration.
Climatic Factors
Relative frequencies of wind in each direction, and wind speed classes. Relative frequencies of atmospheric stability classes. Frequency of precipitation.
Demographic Patterns
Number of people residing, working, recreating in the vicinity, as a function of distance from the source, and of the time of day or week. (i.e. proportion of the time spent in the proximity)
Topographic/Urban Development Features
Locations of: hills; valleys; tall buildings; building complexes; open areas. Vegetation patterns.

Table IV

Fatal accident frequency rates for various activities and occupations

Activity	FAFR
Staying at home (men 16-65)	1
Travelling by train	5
Travelling by car	57
British Industry (ie all premises covered by the Factories Act)	4
Chemical Industry	5
Clothing and footwear	0.15
Timber, furniture etc	3
Metal manufacture, shipbuilding	8
Agriculture	10
Coal mining	40
Railway shunters	45
Construction erectors	67

Industry	THD Waste Production (tonnes/annum)	Average THD Waste per Employee (kg/annum)
Fabricated metal products	7,752	130
Non-ferrous metal industry	8,352	4,200
Electrical machinery manufacture	4,824	34
Electroplating	3,611	450
Manufacture of scientific, photographic & optical equipment	2,245	50
Transport equipment manufacture	2,010	150
Manufacture of plastic products	1,044	11

FIG. 1 MAJOR THD WASTE PRODUCING INDUSTRIES

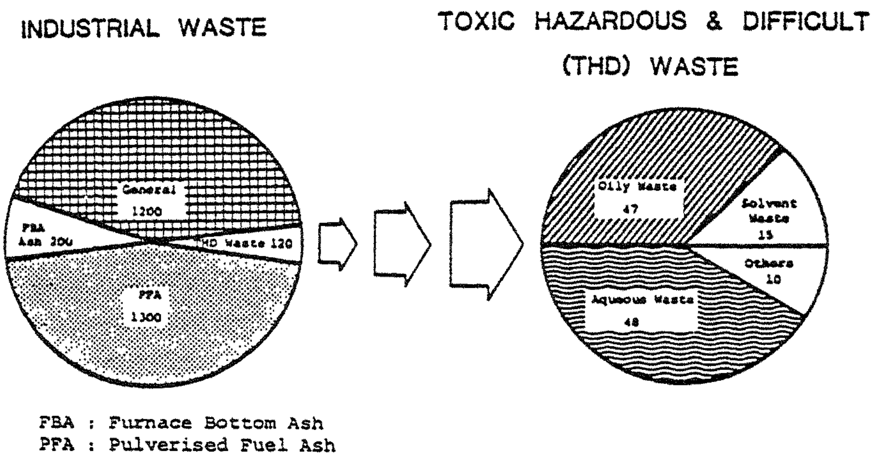


FIG. 2 ESTIMATED PRODUCTION OF TOXIC, HAZARDOUS AND DIFFICULT WASTE IN 1984 (UNIT IN TONNES PER DAY)

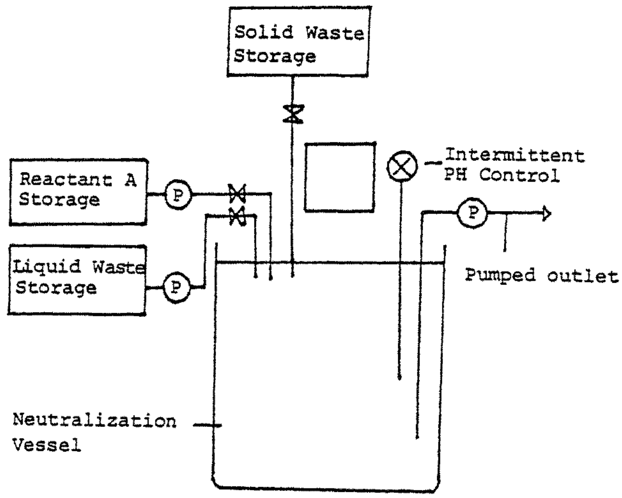
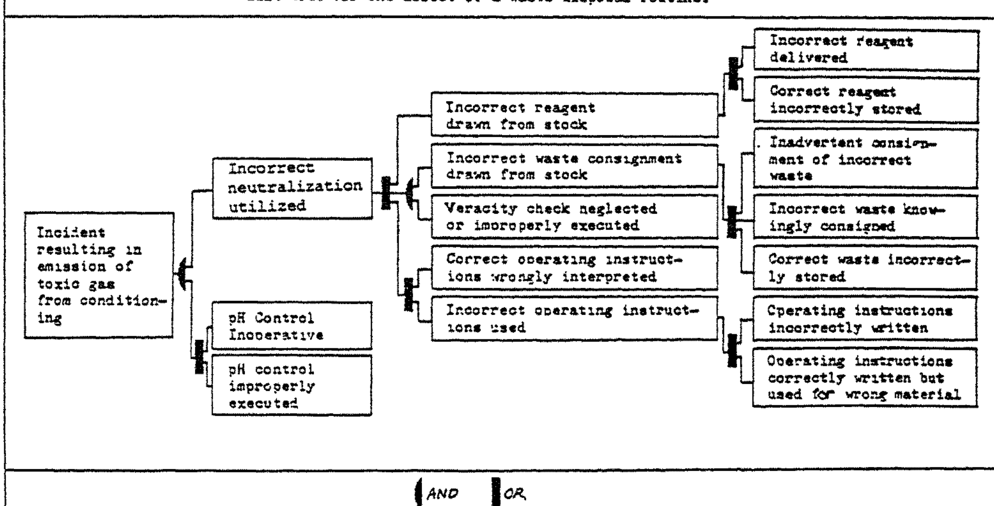


FIGURE 3 Flow diagram for part of a waste disposal routine

FIGURE 4

Fault tree for one aspect of a waste disposal routine.



$$2HNO_3 \rightarrow 2NO_2 + H_2O = 1/2\ O_2$$

is promoted by light and catalysts, especially in strong solutions. Reducing agents such as metals and many metalions will also give rise to oxides of nitrogen, usually nitric oxide NO, sometimes nitrogen dioxide NO_2. NO is oxidized to NO_2 in air.

Nitrogen dioxide is capable of inducing a fatal chemical pneumonitis if inhaled at low concentrations (the Ceiling Value is 5 ppm) so that a potentially serious situation was produced by this action. The wisdom of utilizing the 'slow drainage' method of disposal of strong acids on landfill sites is questionable as it is far from easy to guarantee that any site is secure enough to prevent access by trespassers who might interfere with the flow rate.

Theoretical Quantification of Risk

Any attempt to quantify the likelihood of a hazard developing as a result of a given set of waste handling or treatment procedures must be based on as full an analysis of the procedures adopted as is possible, including a realistic assessment of the likely aberations which may develop. For example, the starting point of such an approach might be an analysis of the harmful gases which could be generated when any of the chemically incompatible substances present on a site inadvertently come into contact. Table I presents some examples of toxic gases which may result from the inadvertant mixture of common but incompatible waste streams. Figure 3 is an example for part of a waste disposal routine and would need to be augmented with details of the reagents and incoming wastes. A series of fault trees can be constructed from this chart to demonstrate the various combinations of circumstances from which hazards may arise. For example, Figure 4 shows some of the circumstances which might result in an emission of toxic gas during a typical neutralization process where acids meet alkalis. The fault tree shown is in outline only; to be fully effective it would be necessary to analyse exhaustively each operation, perhaps producing a series of more detailed fault trees for each, until specific items could be identified against which a numerical value of likely occurrences per year could be entered. The inate variability encountered in the composition of the waste which actually arrives for disposal provides one such category.

Hence, quantification should begin with an investigation to discover a likely figure for the relationship between correct and incorrect consignments. Past experience (not necessarily on an identical site) will indicate that for a certain percentage of acid consignments the theoretically obligatory veracity check will be neglected or improprerly executed. An estimate of the number of times that incorrect material will be present in the alkali stockpile can also be arrived at, as can the number of times that incorrect operating instructions will be used. Hence a combination of estimates can be used to predict the number of times that any one of these possible malfunctions is likely to arise during a specific operating period. Futhermore, it can be postulated that the automatic pH control, which warns of an incipient incident, may itself be inoperative for say 1 per cent of the critical process time, hence 1 in 100 of the potential incident will not be arrested in this section of the fault tree. The annual probability rate for a hazardous substance release from a site which undertakes 5,000 neutralizations per year may be postulated as set out in Table II. (Note that all values in this table are hypothetical).

It follows that one estimate of the number of times per year that incorrect neutralizing will be utilized is I + II + III + IV = 76.25. As it may be argued that the pH control will also fail to detect 1 per cent of these reactions, then (76 x 0.01) 0.76 actual incidents can be predicted per year. In addition, this control itself may be improperly executed for 0.1 per cent of operations (adding a further 0.076) giving a total of 0.83 incidents per year.

At this stage an estimation of the extent of the hazard can be attempted. Through analysis of the volumes and constituents of the various chemical consignments expected and of the various aberrations in procedures which may occur, an estimate of the probabilities that various hazardous materials will be released to the atmosphere in sufficient mass to pose a threat to human health can be developed. It may be determined, for example, that one percent of all incidents will be sufficiently serious to result in a health-threatening release. This one percent figure (or probability of 0.01) represents the summation of the occurrence probabilities for all individual types of incidents and releases which could occur. This 0.01 probability is applied to the estimate (developed earlier) of 0.83 incidents per year, resulting in a number of incidents with health threat or fatality potential of 0.0083 (8.3×10^{-3}) per annum.

The next step in risk assessment is to determine the probability that any people will come into contact with the released toxic gas at a dangerous concentration level (i.e. the probability that adverse health effects or fatalities will occur). Table III lists the parameters required to assess the risk to populations beyond the site boundary. The relative probabilities of various release types, and of releases of materials with various physical, chemical, and toxicological properties (as developed in the foregoing analyses) are important input parameters to this assessment. Other variables in the assessment are: climatic factors (determining the likely direction of travel, and rate of dispersion of released materials); and demographic patterns in the surrounding area (determining the number of people likely to be in the path of the toxic material plume or "puff"). An additional set of parameters which has a bearing on downwind toxic material concentrations are the features of the surrounding topography, and location of tall buildings, etc. (see Table III).

Climatic data need to be taken from a stability wind "rose" for the Hong Kong area, which gives the frequency of occurence of each wind direction and wind speed class, for each atmosphere stability class. From these data, the various climatic conditions which may be in effect at the time of a release incident (and the relative probability of each) can be derived.

One approach to the use of these data in risk assessment involves the selection of various receptor locations, for example the nearest school building, residence, etc. For each selected point, the stability wind rose data is assessed to determine that proportion of the year during which climatic conditions will result in transport of the toxic material to the receptor point, at a dangerous concentration level and for a time interval which is of sufficent duration to result in harm.

Dangerous concentration levels and exposure durations for individual toxic materials are often defined as the short term exposure limit threshold limit value, i.e. TLV (STEL) values, for short-term exposures, and time-weighted average threshold limit values, TLV (TWA) for exposures lasting several hours. These values have been developed for a wide range of materials. Examples of TLV(STEL) values for several compounds are presented in Table I. However the fact that these values have been arrived at with physically fit workers (i.e. aged between 15-65 years) is often cited as a limitation in their generalization. A reduction by 1/10 has been suggested[11]. Certainly the TLV (TWA) will need adjusting if the exposure lasts for longer than a typical shift.

Receptor points under the above-mentioned approach are selected to represent certain populations; students at the school, or residents in the housing block. By evaluating the portion of the time the population is present at that location, (for a school or workplace) or the population present as a function of percent of the time (for a residential area) the probability of this discreet population's exposure to the hazardous materials, and of their experiencing adverse human health impacts, can be assessed.

As an example of such an assessment (using purely hypothetical figures) the determination is made that a ground-level release of a certain mass of hydrogen cyanide (HCN) over several minutes is likely to occur with a frequency of 0.0001 (1×10^{-4}) incidents per annum. These data, along with data regarding the physical and chemical properties of hydrogen cyanide, and the topographic features surrounding the site, are input to a atmospheric transport and fate algorithm. Iterative calculations of the algorithm are then performed, using all combinations of climatic conditions which occur in Hong Kong and their relative frequencies (from the stability wind rose). This results in a determination that a release of the given mass of HCN is likely to result in ambient atmospheric concentrations of at least 15 ppm (the TLV (STEL) for HCN) at receptor point A under several climatic conditions, which together occur 5% of the time on a yearly basis. Receptor point A represents a school, which is occupied 18% of the time on a yearly bais. If these figures are multiplied:

$$1.0 \times 10^{-4} \times 0.05 \times 0.18 = 9.0 \times 10^{-7}$$

The resulting figure is 9.0×10^{-7}. This represents the per-annum probability that the school population will experience atmospheric HCN concentrations above the short-term threshold limit value of 15 ppm.

Similar probability factors can be developed for each inhabited sector of the area surrounding a treatment plant through the use of multiple receptor points, or a receptor grid, in the above analysis. These probability factors, combined with demographic information for each sector, allow a thorough assessment of the risk posed to surrounding populations, expressed in terms of the number of people adversely affected as a function of probability of occurence.

The foregoing is a simplified description of a complex exercise. For example, the number of iterations required to encompass all possible combinations of wind direction, wind speed, and atmospheric stability class, is large enough to make performance of these calculations impractical by hand. The introduction of additional climatic factors (e.g. precipitation), and the need to perform these calculations for numerous potential release types and receptor points further increase its complexity. A risk assessment at this level of detail must generally be performed by computer. Alternatively, if less rigorous estimates of risk are required, reasonable worst-case assumptions can be used for certain parameters (e.g. wind speed, mass of toxic material released, etc.).

It should be noted that the use of any environmental fate and transport model involves a certain degree of uncertainty associated with the assumptions used, and the inherent capability of the method to simulate natural occurrences. These uncertainties need to be recognised and where possible compensated for in the risk assessment.

Assessment of the health risk posed to on-site personnel follows the same principles as outlined above. Because of their frequently close proximity to locations which may release toxic gases, however, treatment plant operators face a greater risk than do populations beyond the site boundary. There is a greater probability of minor releases, which will disperse to harmless concentration levels within a few yards of the source, than there is of releases large enough in magnitude to result in dangerous concentration levels beyond treatment plant site boundaries.

If all of the 8.3×10^{-3} incidents per annum with fatality potential (as determined in the earlier example) result in atmosphere concentrations exceeding the TLV (STEL) within 3 m of the release source, the risk to a specific treatment plant operator from such a hazard may be quantified by analysing his movements, to predict the proportion of the day for which he would be close enough to the neutralizing lagoon to be overcome by an such emission of toxic gas. This might be 2 percent of the time, in which case his personal liability immediately reduces to

$$8.3 \times 10^{-3} \times \frac{2}{100} = 1.6 \times 10^{-4}$$

If a 3-shift system is in operation then the operators chance of being on the shift in question further reduces the probability by one third as follows:

$$11.6 \times 10^{-4} \times \frac{1}{3} = 5.3 \times 10^{-5}$$

Note that this figure represents only the risk of a fatal exposure within 3 meters of the neutralizing lagoon. The same operator is under additional risk from emissions which result in toxic concentration levels at greater distance from the lagoon. If the above number proves to be difficult to comprehend it might be worth turning to the Fatal Accident Frequency Rate (FAFR). This figure expresses the number of accidental fatalities occurring in 10^8 hours of the activity in question, or on the industrial scene, the accidental deaths in a group of 1,000 employees during their working lifetime in that particular trade. As a base line, the FAFR for staying at home is 1, whilst in a typical developed country the average FAFR for industrial accidents may be about 4, (encompassing a range from 0.1 to 60+). Table IV gives details of various trades and also provides figures for certain non industrial activities[12].

To convert the annual expectation of 5.3×10^{-5} figure to FAFR for a worker it is necessary to change this yearly rate into an hourly one by dividing by 2200:

$$5.3 \times 10^{-5}/2200 = 2.5 \times 10^{-8}$$

then multiply by 10^8 to obtain the final FAFR value of 2.5:

$$2.5 \times 10^{-8} \times 10^8 = 2.5$$

The above analysis should have made it clear that the final FAFR value does depend upon the validity of the assumptions which have been made on the frequency of various aberations. Should any of these basic assumptions be changed significantly then the final FAFR will also significantly alter. For example, if it was felt that the estimate that 1% of the incidents would prove sufficiently serious to result in fatalities was incorrect by the value of one decimal place in either direction, then the FAFR would similarly alter in the same fashion, the values ranging from 0.25 to 25.

It should be further noted that the FARF value for an on-site employee and the risk estimate for a hypothetical school population developed in the foregoing discussions were based on a single component of an overall waste treatment facility; the neutralisation lagoon. A complete assessment of risk associated with a waste management program would involve a summation of the results from similar calculations covering all other components and activities. These include the risks associated with: transport of wastes to the facility; all other treatment or handling processes at the facility; transport of treatment residues from the facility; and final disposition of treatment residues.

Discussion

It is clearly very difficult to obtain a direct comparison between the practice of various governments when classifying hazards. For example, even answering the simple question of whether a chemical waste treatment plant should be categorised as a major hazard can be difficult because of the differing interpretation place upon that definition in various countries. For example, the UK now has a unique system for controlling what the Government is pleased to call *special* wastes under the surveillance of a separate inspectorate who are distinct from the group responsible for major hazards. Although the idea of using a yardstick to define the extent of a hazard is attractive, in practice agreement on hazards and levels of risk have proved to be notoriously difficult to obtain. For example, it is easy to see that a simple threshold such as the 'one tonne chlorine' equivalent which was introduced in the UK to allow straight comparisons between major hazards presents a problem of application in transportation, where the result of applying the concept without qualification meant that many of the vehicles moving about public roads became "mobile major hazards".

Surely the issue really turns on the likelihood that the plants proposed for Hong Kong will be operated with sufficient attention to the nature of the risks which are of particular concern in hazardous waste management, bearing in mind the particular circumstances of the territory. It may well be highly significant that the virtual absence of heavy industry from the Hong Kong scene means that many of the highly reactive and intractible chemicals which are common in other countries (such as acid tars) are correspondingly absent. However, although Hong Kong's hazardous waste treatment plants only need to deal with relatively small amounts of materials and these might appear to be relatively innocuous (when compared with certain virgin chemicals), by common consent some sectors of Hong Kong industry exhibit a notorious disregard for the problems created by indiscriminate disposal of corrosive materials. This might mean that much tighter than usual controls need to be instituted and enforced to control the veracity of notifications made concerning such wastes if safe operation is to be ensured. Indeed even in technologically advanced nations, the institution of safe waste disposal routines do not generally enjoy a high priority from industry.

Obvious shortcomings can be identified in the slavish aping of practice from other countries and it is worth repeating that what Hong Kong really needs are standards which have been evolved with its unique problems in mind (such as the extreme pressures on physical space, the juxtaposition of industry and domestic development, etc.). Whilst hazardous waste treatment plants do not necessarily stand particularly high on any absolute scale of major hazard potential they are particularly prone to problems associated with the ease with which statutory controls can be evaded. Finally the authors' experience whilst researching hazards at waste treatment plants in Europe and the USA leads to the suggestion that the British approach in identifying a totally separate group of officers with the duty of proving surveillance over standards has some merit in providing a platform from which an objective assessment can be made - witness the highly critical comments made by the Chief Hazardous Waste Inspector in his latest Annual Report[13].

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Fishermens' Children and Lead Poisoning

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Introduction

Fishermen in Southeast Asia lead a unique life style, very different from people in the urban areas or rural districts. They are very traditional, very inbred and they have strong family ties. The whole family lives on a fishing boat. Often, a large extended family with three generations lives together on a single fishing junk less than 30 feet long. The whole family goes on fishing trips of 1 - 3 weeks duration, returning to dry land for only a few days to sell their catches and prepare for the next fishing expedition. Their pre-school children are at a disadvantage because of limitations of space and lack of educational exposure to promote early childhood development. They do not have ready access to medical and health care facilities and are exposed to health hazards related to their parents' occupation and their home environment. Drowning, for example, occurs at a much higher frequency among fishermens' children than in urban children[1]. Acute suffocation of toddlers by neck restrainers, used by parents to prevent them from falling off the boat is also often encountered. Readily accessible lead-containing objects, such as lead weights, cooking utensils and coloured toys together with frequent mouthing habits in these children render lead poisoning a significant health problem.

An observation made in 1970 (unpublished)[2] showed that fishermens' children attending the Aberdeen Maternal and Child Health Centre had lower haemoglobin levels than children attending the Sai Ying Pun clinic. The Aberdeen MCH served the fishing community while the Sai Ying Pun OPD served mainly city children. Preliminary assessment at that time suggested that nutritional deficiency was probably the most important cause for the difference. As the fishermen are often at sea for weeks, they were unable to bring enough red meat or fresh vegetables, depriving their children of a good source of nutrients, especially iron. They were also socio-economically under-privileged, living on a very substandard diet with multiple nutritional deficiencies. Diet was therefore thought to be the most important factor for their relative anaemia, and the possibility of lead as a contributing factor was not considered.

Recent Experience

Records from our department indicate that only a few cases of symptomatic lead poisoning were diagnosed before 1981; all of them however were fishermens' children. Subsequent to 1981 we have admitted a 1 1/2 year old girl from a fisherman's family with clinical feature of acute bronchiolitis. The child was found to be anaemic with Hb 7 gm/dl and she developed respiratory failure soon after admission. Her peripheral blood showed reticulocytosis of 12% and basophilic stippling of the red blood cells. Her chest X-ray revealed dense opaque lines at the metaphyseal ends of the long bones. The features were compatible with lead poisoning. This was confirmed by a high blood lead level exceeding 120μg/dl. She developed mild encephalopathy the day following admission which was associated with mild and transient peripheral neuropathy. She continued to show protracted bilateral diaphragmatic paralysis necessitating ventilator care for 2 1/2 months. She was treated with chelation therapy and eventually recovered, breathing on her own with no demonstrable neurologic deficit at the time of discharge after a 3-month stay in the hospital. The unusual phrenic nerve neuropathy (diaphragmatic paralysis) of 2 1/2 months duration in this girl has rekindled our interest to investigate the health hazards related to the fishermens' children, and this time we were keenly interested to study the problem of lead overload.

Environmental Factors

Visits to the home of this patient revealed a number of intriguing problems. Her mother and her two elder siblings were found to have clinical, haematologic and radiologic evidence of lead poisoning. A number of hazardous factors were also identified which could have increased the lead intake of the children. Excessive mouthing (or pica) was a common habit in the children. They played with cheap toys coated with lead containing paints. Lead weights used in fishing lines and fishing nets were found scattered all over the place, including the fresh water tank and cooking utensils. The children were often seen biting the toys and lead weights during the visit. Lead containing paints which were used on the boat for painting the cabin were lying freely around. The family also used traditional Chinese ceramic plates for steaming fish. These plates had colored patterns on the inside which were also high in lead content. Water samples taken from the fresh water tank showed the presence of some lead. A probable cause was the family's practice of opening the lid of the tank in order to receive rain water. This resulted in acidification of the water, leaching lead from the lead weights which were in the tanks.

Indeed subsequent field visits to other fishing boats revealed uniformly identical findings. As the majority of the fishermen are very suspicious of potential harmful effects of venipuncture, full scale venous blood analysis was rendered impossible. Only a very small amount of capillary blood was obtained for examination. Of 109 children between 1-14 years examined, 20.3% were detected to have blood lead levels exceeding 30 μg/dl, more than half were over 40 μg/dl. Eight of these children subsequently were admitted to the hospital and all were found to have venous blood lead levels over 32.5 μg/dl. Five of them also demonstrated positive EDTA provocative test indicating unacceptable lead overload requiring chelation therapy. Two other fishermens' children from the same community were admitted around the same time (1985-86) for atypical febrile seizures. Both were detected to have blood lead levels of 193 μg/dl and 66 μg/dl respectively and roentgenographic and hematologic evidence of lead poisoning. Their diagnosis could have been missed in a busy hospital if suspicion for lead toxicity was not heightened. Apparently lead poisoning is a unique problem among the fishing community and not so much in the city folks.

Effects of Diet

Careful scrutiny of the children's diet has revealed a number of interesting features which may signigicantly affect the children's health and in particular, lead absorption. In a study on local Chinese weaning habits, Li and her colleagues[3] have found a significant proportion of the diets to be of sub-optimal caloric content, and deficient in iron, vitamins and calcium in terms of WHO Western Pacific Regional recommendations. In the present study, analysis of the fishermens' children's diet has shown a very similar, and even more significant, trend of such deficiencies (Table 2). Salt-fish in small amounts was frequently consumed as a replacement for other meat containing dishes with rice as the staple food.

Numerous studies have indicated that nutritional status can influence susceptibility to lead toxicity. Low calcium diets have been found to enhance absorption and facilitate deposition of lead in tissues in both experimental[4,5] and clinical[6,7] situations. Infants and toddlers [7] appear to be particularly vulnerable. The sub-normal dietary calcium intake of the fishermens' children apparently plays an important role in the prevalence of lead toxicity among them.

The iron-deficient diet[8,9] and low vitamin C[10] intake are also known factors increasing lead absorption from the gastro-intestinal tract, and these deficiencies are also present in the fishermens' children. Although the calcium intake and vitamin D content in the diet is generally sub-optimal among small children, including the fishermens' children in Hong Kong, vitamin-D deficiency rickets is

Table 1 RISK FACTORS FOR LEAD OVERLOAD IN THE FISHERMAN'S CHILDREN

Anaemia in the children

Excessive mouthing habits

Ready access to lead-objects

- Lead weights
- Lead paints
- Cheap coloured toys

Lead-coloured ceremic plates for meals

Dietary deficiencies :

- calories, iron, calcium, Vitamin C

Excessive solar exposure

Table 2 FISHERMAN CHILDREN's DIET

Items	Below WHO's RDA
Calories	89.8 %
Protein	14.3 %
Iron	67.3 %
Calcium	89.8 %
Vitamin D	69.2 %
Vitamin C	54.8 %

Analysis of 49 children's diet by 'immediate 24-hour recall method'

RDA = Recommended Daily Allowance

Table 3 LEAD LEACHED FROM CERAMIC PLATES

pH \ Time	Room Temperature				Steaming Condition				
	0	24 hrs	48 h	96 h	0'	1 h	2 h	24 h	48 h
7	0.02	2.2	4.1	4.3*	0.04	0.05	0.9	7	7.5*
2.5	4.4	780	980	1020	5.8	1340	2100	2500	2730
2.4	4.1	630	913	1019	7.5	1340	2500	2700	3060
1.1	48	1500	1990	2360	51	2400	4000	3800	3940
0.1	60	750	1070	845+	52	4300+	1700+	900+	1130+

N.B.

1) * All values are in mg Pb/L

2) + Presence of precipitates in the dishes suggestive of crystals of lead salts

3) Constituents for the pH solution :
a) Distilled water → pH 7
b) 3% acetic acid for pH 2.5
c) 5% acetic acid for pH 2.4
d) 0.1 M HCl for pH 1.1
e) 1.0 M HCl for pH 0.1

4) The yellow and red letter plates leached higher amount of lead than the green coloured plates under similar conditions

rarely encountered except in new immigrants. One reason must be due to the ready availability of sunlight, increasing the in-vivo synthesis of adequate amounts of vitamin-D for growth purposes. Moreover, the majority of these children with such deficiencies are also receiving a sub-caloric intake (Table 2). This was reflected in their growth rate during the weaning stage which was slower than in children in other countries[11]. Absence of a rapid growth rate to out-strip the demand for calcium deposition in bone is probably the explanation for the rarity of rickets in these children despite receiving sub-optimal dietary calcium and vitamin-D intake.

Constant exposure to the sun with enhanced production of endogenous vitamin-D in these children may also have a significant contribution to lead poisoning. Indeed, increased solar exposure in humans[12] and increased vitamin D and 1,25 dihydroxycholecalciferol intake in animals[13] have been shown to increase lead absorption and lead toxicity. The possibility of increased availability of vitamin D in these children represents another factor known to potentiate lead overload.

We have obtained similar ceramic dishes used by these fishermen and reconstructed simulated cooking conditions using these utensils. We were able to show that under the usual looking conditions, lead is leached out of the coloured ceramic plates, especially when they contained an acid sauce for steaming fish (Table 3). These studies have further identified another source of dietary lead for the fisherman's children who already have many demonstrated features of enhanced lead absorption and toxicity.

The Problem of Lead Poisoning

A simultaneous survey was conducted by us[14] to delineate the blood lead levels in school children scattered over various districts of Hong Hong. A large group of over 6000 children were examined, 0.16% of them were detected to have levels exceeding 30 μg/dl. The prevalence rate was significantly lower compared to children in other big cities[15]. Yet the frequency of unacceptably high blood levels was much higher among the fishermens' children.

It has been shown that overt or subtle abnormalities in developmental and cognitive functions occur in children with high blood lead levels and even in those with levels less than 50 μg/dl[16]. Over the past years, health authorities have been lowering the maximum acceptable blood lead level in young children, recently down to 25 μg/dl[17]. The high blood levels demonstrated in our children must therefore represent a major deviation from modern health standards. Our findings have indicated a need to launch a larger scale study to increase our understanding of the magnitude of the problem and to institute health education programmes to help the fishermen improve their living conditions.

All over Southeast Asia, fishermen live alike. They live on similar fishing junks or sampans (smaller boats); they use the same lead weights for fishing lines and nets; they are of equivalent socio-economic status within their own societies; their eating habits and traditions of child rearing are also similar. We suspect that their children would be just as susceptible to lead overload and toxicity as their Hong Kong counterparts.

Conclusion

We have presented some local background information which have led us to study the problem of lead poisoning in fisherman's children in Hong Kong. We have found a high frequency of lead toxicity among these children and have also identified a number of possible predisposing factors. We think that our findings have significant bearing on the health of the children of fishing communities all over Southeast Asia, as these people live in a similar if not identical environments, traditions and living conditions.

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Need Pig Wastes Pollute?

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Abstract

Much of the pollution in Hong Kong's coastal waters is land-generated and various studies on Hong Kong's streams have stressed the magnitude of the problem. Agricultural wastes, particularly pig-manure, have been shown to be the major contributor to stream pollution both in the New Territories and in parts of urban Hong Kong. Government schemes to compost and dispose of pig-manure have not been wholly successful and this paper offers an alternative scheme to utilise pig-waste as a substrate for vermicomposting. Results indicate that a Japanese strain of *Eisenia foetida* is capable of rapid growth in pig-slurry resulting in a massive increase in worm protein biomass which can be fed to ducks and fish while the residual worm-cast can be used as a nutritionally balanced soil conditioner. Figures extrapolated from a pilot scheme indicate that a substantial amount of pig-slurry could be treated on a comparatively small area of land.

Historical Background to Marine and Stream Pollution in Hong Kong

Morton [(1)] described the Hong-Kong seashore as an environment in crisis, and drew attention to the impact of pollution as one of the major contributing factors. Hodgkiss [(2)] showed that much of this pollution is land-generated and reaches the sea via streams, so that any attempt to alleviate pollution of the seashore must begin with an improvement in stream-water quality.

The pollution of these streams was first brought to the attention of the Hong Kong Government in 1968 [(3)]. Deteriorating water-quality was noted and it was concluded that pollution of stream courses would create even greater problems in the future, unless steps were taken for the adequate disposal of agricultural wastes, domestic sewage and refuse, and industrial wastes. This warning was repeated in 1972 [(4)] when EPCOM stated that the Government should establish a regular monitoring service of its coastal waters and streams under a single authority.

As part of a water-resources survey [(5)], data was presented on water quality in the North West New Territories for 1972. These data, when compared with the results of a survey carried out between 1965 and 1967, revealed that there had been a marked increase in the level of pollution and that, whereas streams in the hillside areas were generally still free from significant pollution, as they entered the lowland areas their quality sharply deteriorated, so that by the time they reached floodplain level they were grossly polluted.

It was concluded that the grossly polluted nature of all the streams passing through the lowland areas resulted mainly from agricultural wastes and excreta, but that human sewage contributed a substantial pollution load [equivalent to between 10 to 20% of the agricultural load). Industrial effluents and domestic refuse dumped into watercourses, although unsightly, were considered to be of less significance except in a few localities.

A subsequent investigation of stream pollution covering all the rural New Territories [(6)] concluded that 40% of all stream-courses examined were polluted, and that, in the lowlands, the stream-courses with few exceptions were either polluted or grossly polluted.

Based on these earlier studies, consultants were appointed in 1974 to make recommendations to the Government concerning the controls required for the protection of the Hong Kong environment. They showed [(7, 8)] that stream pollution had become steadily worse since 1968 and, as a result, an Environment Branch and Environmental Protection Unit were established in 1977. A number of more localized studies have been carried out subsequent to these consultants' reports which further highlight the pollution problems in Hong Kong streams [(9, 10, 11, 12, 13)].

The Magnitude of the Problem

The first substantial data on stream pollution in Hong Kong [(5)] revealed that, on the basis of their BOD value and faecal coliform content, all the lowland streams in the North West New Territories were grossly polluted, while considerable lengths were also grossly polluted on the basis of their ammoniacal nitrogen content, and some parts had excessive amounts of arsenic and cyanide. Moreover, 50% of all samples contained pathogenic bacteria of the *Salmonella* group (Table 1). The same consultants broadened this study in 1972 and 1973 to include over 250 miles (400 km) of streams in the rural New Territories [(6)], and their findings revealed that most of the New Territories' streams investigated were polluted on the basis of their BOD values, whereas 36.8% were grossly polluted and 27.6% merely polluted on the basis of their ammoniacal nitrogen contents (Table I).

The consultants further estimated the pollution loads (in terms of BOD) that were imposed on Hong Kong streams by various pollutants as shown in Table II.

This table also presents the calculations of Environmental Resources Limited concerning pollution loads in 1974 and their estimates for 1984 [7, 8].

For the 1984 projections, it was assumed that, by that year, collection of agricultural wastes would lead to a 47% decrease in the agricultural BOD load since the 1972-73 results, and hence a 33% decrease in the overall BOD load. In fact, nothing approaching this 47% decrease is likely to have been achieved, as little progress had been made by 1984 in establishing a collection service - except in some localized areas where chicken and pig manure is collected for treatment at plants operated by the Agriculture and Fisheries Department.

Agricultural effluents were highlighted by both consultants [6, 8] as the major pollution problem, and Environmental Resources Limited described the situation in Hong Kong streams as one where 'these effluents are poured into the stream courses, settle to form putrefying and obnoxious banks which create dams, and the consequent further accumulation of solids of agricultural and domestic origin aggravate the situation even more'. Both consultants envisaged an even greater deterioration of water quality in the future unless remedial action was taken.

Since the final report by Environmental Resources Limited [8], more localized (but also more detailed) studies have been carried out, and Table III presents a summary of the results from two such studies covering six streams leading into Tolo Harbour in the North East New Territories [9, 11, 12].

Based on the same standards as those applied to Table I data, four of these streams were shown to be suffering from organic pollution, though not to the same extent as the streams in the North West New Territories. Until comparatively recently this area was little affected by stream pollution, but the development of housing, industrial estates and pig farming, in the area has now made its impact. Even during the period of these investigations, a decline in water quality was obvious, and thus, unless action is taken, these streams will soon join the ranks of Hong Kong's grossly polluted streams.

Effects and Amplications of Stream Pollution in Hong Kong

The state of the lowland streams in the North-Western New Territories ruled out any possibility of achieving a technically and economically viable water abstraction scheme in that area [5] and, in terms of providing alternative supplies, a financial loss of HK$25 million per annum was predicted.

Water from a number of New Territories streams (for example the River Indus) is impounded into the Plover Cove Reservoir. However, because of the conditions in such streams, water is only abstracted when ammoniacal nitrogen

Table I
Pollution Status of Hong Kong Streams, based on contents of (a) BOD, (b) Ammoniacal Nitrogen, (c) Faecal Coliform Bacteria, (d) Pathogenic Bacteria, and (e) Toxic Substances

Parameter (see heading)	North Western Water Scheme Pollution Study(5)	New Territories Stream Pollution Study (6)	Pollution Status
(a)	Averaged 12 mg/dm³ or more under average conditions	95% of samples in excess of 12 mg/dm³	Grossly polluted[1]
(b)	Dry season Values of 300 mg/dm³ and above in some lowland streams Wet season Values in excess of 10 mg/dm³ in most lowland streams	27 6% of samples above 1 mg/dm³ and 36 8% above 12 mg/dm³	Polluted to grossly polluted[2]
(c)	Minimum value was 180 000 per 100 ml Maximum value was 54 × 10^6 per 100 ml		Unfit for recreational usage[3]
(d)	50% of samples contained pathogens of the *Salmonella* group		Dangerous
(e)	Arsenic and cyanide were 5 to 25 times more than the recommended limit of 0 05 mg/dm³		Dangerous[4]

Standards employed
[1] Department of the Environment (Reference 21)
$<$2 mg/dm³ = clean 2 5 mg/dm³ = fairly clean 5 10 mg/dm³ = doubtful quality 10 12 mg/dm³ = polluted and $>$12 mg/dm³ = grossly polluted
[2] Local standard based on Trent River Authority guidelines (Reference 6)
$<$1 mg/dm³ = clean 1 10 mg/dm³ = polluted and $>$12 mg/dm³ = grossly polluted
[3] Federal Water Pollution Control Administration (Reference 22)
Less then 2000 per 100 ml for secondary contact and less than 200 per 100 ml for primary contact
[4] World Health Organisation recommended limit (Reference 7)
Less than 0 05 mg/dm³ *is safe*

Table II
Total Stream Pollution loads in Terms of kg/day of BOD Discharge

Effluent	1972 73 results	%	1974 calculations	%	1984 projections	%
Industrial	11 906	10	1 668	3	2 723	8
Agricultural	34 935	67	44 129	86	23 352	68
Domestic	5 449	23	5 790	11	8 272	24
Total load	52 290	100	51 587	100	34 347	100

Table III
Mean NH_3-N BOD and faecal coliform levels in six streams entering Tolo Harbour

Stream	Section	NH_3 N (mg/dm³)	BOD (mg/dm³)	Faecal Coliform Bacteria (numbers/100 ml)
Tai Shui Hang	Source	0 016	4 18	96
	Midcourse	0 013	2 83	89
	Mouth	0 155	4 54	135
Shing Mun	Source	0 02	3 02	174
	Midcourse	6 03*	5 39°	97724*
	Mouth	3 22*	3 24	45709*
Tai Po	Source	2 77*	5 11°	56234*
	Midcourse	2 93*	6 3°	29512*
	Mouth	1 08*	6 29°	10471*
Lam Tsuen	Source	0 048	4 07	34674*
	Midcourse	1 304*	21 39**	40738*
	Mouth	2 494*	47 15**	56234*
Tai Po Kau	Source	0 03	1 3	219
	Midcourse	0 062	1 2	262
	Mouth	0 061	1 4	414
Sha Tin	Source	0 099	3 25	300
	Mouth	1 378*	12 0*	2840*

** = grossly polluted * = polluted ° = dubious quality levels fall below 4 mg per dm^3, and thus only about 50% of the potential source is utilized, leading to an estimated financial loss of HK$22 million per annum (6).

Both pathogenic organisms and potentially toxic substances are present in the streams and thus constitute a possible risk to public health. Although the stream water is unlikely to be consumed because of its appearance and smell, it is used for irrigation and diverted into fish ponds and thus poses a threat by contamination of foodstuffs. The amenity value of this part of the Hong Kong countryside is also affected by the unsightliness of many of the streams, and by the smells which emanate from them.

As more and more industry moves into the New Territories, poor quality of the water abstracted for use by industry could be a cause for concern. At present, industrialists have made no public comments concerning water quality; but this is probably because they know that they return their used water to streams without treatment, and thereby contribute to the pollution load themselves (7).

The Pig Waste Problem

With a population of over 5.5 million, Hong Kong's ratio of population to land is among the highest in the world. In addition, there are some 6-7 million poultry and 0.5 million pigs on local farms (14) to supply the requirement for 66 per cent of the live poultry and 18 per cent of live pigs used annually in the territory.

The quantity of refuse and dried animal manure generated by the people, the pigs and poultry amounts to over 2.2 million tonnes per annum and, because of a lack of sufficient land, the problem of organic wastes in Hong Kong has been mostly concerned with disposal rather than with the utilization of such wastes. Most of the animal wastes are discharged into water courses without any treatment, and the large amounts of pig wastes in particular have thus caused serious pollution to the water courses of Hong Kong in the last decade. The BOD loading on streams from these wastes is equivalent to four times the municipal pollution strength.

Alternative Disposal Methods

The Hong Kong Government is greatly concerned with the continuous decline of the environment and has established an Agricultural Waste Treatment Unit to evaluate the problem and to look at various means to tackle this formidable task. Since August, 1980 an Agricultural Waste Control Division has also been set up in the Agriculture & Fisheries Department to develop operational plans and legislation for controlling pollution caused by agricultural wastes. The Government has been investigationg various means of recycling animal wastes, e.g. the drying of pig and poultry manures with mechanical agitated heaters for use as a fertilizer/soil conditioner and pelleting of dried animal manure as fish feed to avoid autrophication of fish ponds etc. Isaac & Rewell [15] calculated that 86% of fresh water pollution in Hong Kong arose directly from agricultural wastes of which 80% originated from pigs and the remainder from poultry.

In 1978 Hong Kong became a participant in the FAO (UNDP) Regional Project on organic recycling in Asia and through participation in the scheme, the awareness of the importance of recommencing to use organic wastes for agricultural purposes has gradually been increased. The Government has committed funds for an organic recycling project with a view to producing an alternative to dumping of such wastes and it is very encouraging to see that a programme for organic waste disposal in Hong Kong has gradually developed from purely disposal to an introductory stage of organic recycling in recent years.

The collection and disposal of pig manure, which is a notoriously unpleasant form of animal waste since it is generally found as a slurry with a very unpleasant odour, is a serious and, as yet, unresolved problem for government agencies in Hong Kong. A pilot plant for pig manure treatment was set up in Ngau Tam Mei which treats 15 tonnes of pig manure daily (i.e. equivalent to ≅ 16% of Hong Kong's daily production. The fresh slurry (with a water content ≅ 85%) is placed in concrete bays where it is aerated by continual turning by means of a front-end-loader for the first five days. Thereafter, this process is repeated every fourth day until the 20th day. At this stage approximately 12.75 tonnes of the turned manure is added to a fresh 15 tonnes batch of fresh manure. The final product, mixed with sawdust (≅ 30% v/v/), is sold to farmers and landscape designers as a soil conditioner.

The process outlined above is costly, labour intensive, socially unacceptable and results in a product that is viewed with suspicion by potential users.

More recently the Government of Hong Kong has formulated plans to spend $440 million on a ten year programme to tackle the animal waste problem in the territory. The scheme plans to ban all livestock farming in urban and new-town areas and contractors will be employed to collect, on a daily basis, animal waste from designated road-side collection points and deliver it to composting or consolidation plants for subsequent disposal.

However, in all of the schemes so far proposed the end result is the accumulation of a gigantic pile of animal manure awaiting either further treatment and/or disposal. At this stage no concrete plans for disposal have been suggested and it is possible that the collection of all of the territory's waste to one or a few large dumps may exacerbate rather than relieve the problem.

Another approach to the disposal of organic wastes, such as pig manure, is the production of biogas (methane) following the fermentation of the substrate under anaerobic conditions. The system used in biogas production is simple, cheap and effective and, in rural communities in mainland China, has been exploited on a wide scale to produce, in many instances for the first time, a supply of gas for heating and a lighting source to many communes and rural hamlets. In Hong Kong the various sewage treatment plants in the New Territories generate in addition to their normal function, biogas which is used solely for the purpose of heating water to maintain the correct level of temperature in the digestor tanks; excess biogas is removed in a waste gas burner. No attempt has been made to utilise biogas further presumable because of the ready availability of electricity to all parts of the New Territories.

Another approach to the problem of pig waste disposal has been made in this department by *vermicomposting* the manure to produce a final product that is odourless, nutrient rich and readily acceptable to the lay public and, at the same time, the process generates a secondary product - animal protein - that can be utilised as an animal feed which can be readily used by fish- and duck-breeders.

The ability of earthworms to promote the rapid decomposition of organic materials has been recorded for decades and vermicomposting as a principal originates from the fact that earthworms feed mainly on microorganisms in the organic waste material but in the process of feeding they very effectively fragment the waste substrate thereby increasing its surface area for further microbial colonisation. The cast produced by worms feeding on organic substrate is an extremely homogeneous, fertile material suitable for plant growth [16] while the worms themselves provide a protein source for animal feed [17].

In brief, the procedures which have been used are as follows:

Worm breeding

Preliminary experiments with worms from various sources in Asia showed that the most prolific breeder was a stock of *Eisenia foetida* from Japan and this stock was selected for the present investigation. Approximately 0.25 kg of worms (≅ 500 in number) were placed in wooden breeding boxes measuring 1 m x 1 m x 0.5 m containing a 0.25 m deep 50:50 mixture of peat moss and well composted cow manure.

Pig manure substrate

Attempts to grow *E. foetida* directly on untreated pig manure (collected from Ngau Tam Mei Composting Plant) were entirely unsuccessful resulting in the rapid death of all worms within 24 hours. When the pH was adjusted to 5 and the manure composted at 55°C until the pH had reached 7, worms ingested the manure but were unable to burrow and live in it as bedding material. The addition of 4% calcium sulphate to the untreated pig manure followed by composting for 2 days resulted in an acceptable material. The ultimate treatment however was achieved by washing the 3 day old composted manure (supplemented with calcium sulphate) and allowing the excess water to drain through a suspended hessian sack. The resultant material proved to be totally acceptable as a feed for worms and was used for the remainder of the investigation. Worms were fed with this feed for 10 days and an assessment made of the increased biomass of the worm population, the number of unhatched cocoons and consumption rate of feed per day. These results indicate that, following the stabilisation of pig manure, the feed was totally acceptable to our test worms. For example, increases in worm population density in the breeding boxes are reflected in a drop in the number of cocoons produced indicating a dramatic increase in individual worm biomass. However, as food was never limiting, one can only conclude that the factor responsible for lowered cocoon production was the increased accumulation of worm cast.

Worm cast analysis

During their consumption of pig manure the worm stock produce their casts on the bedding surface. This material was collected at.the end of the 10 days feeding period and air dried for 48 hours under draught after which it was ground in a mortar and pestle and passed through a 0.1 mm sieve. Analysis of this cast indicated that the effect of feeding worm on washed stabilised pig manure was: a 27.5% loss in organic matter; a 8% N_2 assimilation rate; ingesta assimilation approximated to 1.5% after total feed imput; humus content increased 40-60% - a figure higher than natural composting processes.

Worm protein

Although fresh worms can be successfully fed to ducks and fish, storage of large quantities of worms presents a problem. Firstly, because dead worms exude caelomic fluid with an unpleasant smell and secondly, the fats and phospholipids present in the worm oxidise rapidly giving rise to a characteristic "fishy" smell which repels fish when stored worms are used as feed.

Attempts were made to remove fats and phospholipids from fresh - worms by means of semi-polar solvents and to treat the residual protein in a manner to enhance its convenient storage. This material was then used in feed trials.

Feed trials

These were carried out on the following fresh water fish:

(i) *Carassium auratus* L. (common name: Goldfish)
(ii) *Cirrhinus molitorella* C & V. (common name: Mud Carp)
(iii) *Clarias fuscus* (lacepede) (common name: Catfish)
(iv) *Gambusia affinis* (Baird and Girard) (common name: Mosquito Fish)
(v) *Ophiocephalus maculatus* (Lacepede) (common name: Snake head)

All fish weighed between 200-250 g and 5 of each type were held in fresh water aquaria and fed daily for 30 days on the crude protein. The usefulness of worm-protein as an animal feed has been reported previously and our experiments indicate that once solvent extraction procedures have been applied to worm tissue in order to eradicate potentially oxidisable materials such as fats, the resultant protein preparation is acceptable to fish; we have also assessed its acceptability to ducks and other commercially exploited fish with successful results.

Conclusion

The generation of some 30,000 tonnes of pig manure annually in Hong Kong has posed a major environmental threat for some years and, while the Government has taken steps to partially alleviate the situation, the composting plant at Ngau Tam Mei and the Sai Kung drying plant can only treat approximately 28% of Hong Kong's annual production of pig manure. This leaves a residue of some 22,000 tonnes which are washed into Hong Kong's streams and ultimately onto the beaches. The pollution hazards of this amount of untreated manure are enormous and *any* new measure to reduce the amount of pollution would be welcome. It was with this object in mind that the vermicomposting research referred to in this paper was initiated.

Composting of organic wastes is an ancient practice and vermicomposting *per se* was developed from basic research carried out on earthworm management programmes set up at Rothampsted in the 1940's and 1950's. By the mid-70s scientists were actively engaged in studying the power of earthworms to covert organic wastes from diverse sources and this has been summarised in *"The workshop on the role of earthworm in the stabilization of organic wastes"* (18). Continued studies suggested that vermicomposting is a technology for treating waste with a low energy consumption rate. Waste materials are stabilised faster and can be dried faster; pathogens such as *Salmonella* can be destroyed more rapidly (19); protein recovered as worm meal represents a high efficiency method for animal protein production.

Trial experiments on a pilot-scale system on a typical Hong Kong pig farm resulted in the following parameters. 1 tonne of pig manure with a composting cycle of 7 days requires 237 kg of *E. foetida* (i.e. 640,000 mature worms) in an area 47.5 m^2. Extrapolating this data to a system generating 93 tonnes of pig manure daily (Hong Kong's present production rate) requires a piece of land 4,400 m^2 to produce 83.7 tonnes of fine quality dried worm cast and a 22 tonnes of fresh worm protein.

One important area of worm-protein acceptibility that has to be discussed is the possible cycling of toxic materials and heavy metal contamination within the food chain i.e. the protein of worms fed on contaminated sewage when fed to fish for human consumption might result in an accumulation of deleterious substances in fish protein which could thus possibly be ingested by man.

In the overall context of waste management and resource recovery, two important concepts must be considered, viz. "co-disposal" (17) and the "Bioplex" (20). Co-disposal means the mixing of two or more wastes in order to optimize the handling of each separate one and in this context the vermicomposting of sawdust on a large scale is being examined for its practicability. Since animal manure contains high levels of nitrogen, the co-disposal principle is particularly apt, in that sawdust mixed with pig manure could provide a suitable feed for worms. The Bioplex concept embraces any system wherein "the biological conversion of wastes consists of exploiting the chemical activities of living creatures in such a way that the waste from one creature becomes the food for another". This concept can take many forms, such as a simple network or a more comprehensive approach. Adoption of such a concept would mean, of course, a move away from intensive monoculture and towards a mixed- farming concept, and this would again nessitate a significant change in attitude and outlook by the producer. The more important long-term solution will be to convince producers that they would consider their wastes not as a problem but as significant economic resources. Producers will thus have to consider themselves not just as pork producers, or egg producers, but as compost producers as well Alternatively those producers who do not share the idea as vermiculturalists might need to collaborate with those who do. At present, composting is the only solid waste disposal process that salvages the organic fraction, and vermicomposting, in addition, yields high quality protein from the worms' biomass as a by-product. The recycling and reclamation of waster materials by vermicomposting cannot be ignored by the decision makers of solid waste disposal systems as they investigate means of reducing the pollution caused by pig wastes.

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Enteric Bacteria Decay in Seawater and Outfall Design

S.H. Wong

Introduction

The sea has long been used as a receptacle for human wastes. Raw sewage, treated effluent, and some sludges are directly or indirectly discharged into the marine environment, in particular the estuarine and coastal waters which are valuable natural resources for shellfish growing, fishing, and recreation. Although the natural self-purification processes of the receiving waters can help to maintain the quality of coastal waters for beneficial uses, such processes have limited capacities and therefore may not be able to keep pace with water pollution in some developed urban cities along coastlines. A common solution to such a problem is a properly designed wastewater treatment facility plus a marine outfall.

Marine outfalls have been constructed to replace existing sea wall outfalls in old urban areas or as proper outlets of sewerage systems in newly developed areas. Placing an outfall in the correct direction and at an appropriate distance from shore is, in fact, an optimization of the self-purification capacity of natural waters. Once the bacterial water quality standard has been determined, then the initial dilution, dispersion, and bacterial decay of receiving waters are the major parameters involved in design calculations of submarine outfalls.

Pearson, *et al* (1) and Gameson (2) have both pointed out that the bacterial decay rate is the most sensitive parameter in determining the appropriate length of outfalls so that the discharge can meet the pre-determined bacterial water quality standard. Unfortunately, bacterial decay rates cannot be accurately determined because they are affected by many environmental factors which probably also interact with each other. Therefore, direct field measurement is considered to be the most appropriate method to obtain the bacterial decay rate for outfall design. However, field measurements are very expensive and also subject to seasonal variations if only one or two measurements are made. Laboratory techniques, on the other hand, have not been well developed and fully accepted as a standard measurement of bacterial decay rates in seawater. Nevertheless, many outfalls have already been designed based on the decay rates obtained from laboratory studies which are now considered inadequate. This review paper will focus on the following areas of the problem:

(1) bacterial indicator of recreational water quality;

(2) significance of seawater bacterial decay rate in outfall design;
(3) bacterial decay rate in seawater.

Bacterial Indicators of Recreational Water Quality

As one of the most important resources on earth, water is used in a wide spectrum of human activities. The suitability of a water body for a specific use is determined by its quality which is defined in terms of physical, chemical and biological parameters. When water is used for purposes which may result in direct or indirect contact with man, the biological characteristics of the water quality, especially the bacterial concentrations, become most important because bacterial water quality is related to contamination in the water of fecal materials which sometimes contain pathogens. The risk of contacting the pathogens from the water is generally helieved to have a positive correlation with the amount of fecal contamination in the water. In order to quantify such a risk when water is used for recreational purposes, it is necessary to have a bacterial water quality indicator which has a high correlation between its level and the rate of gastro-intestinal disease associated with the use of the water for recreational purposes. In searching for a satisfactory bacterial indicator of recreational water quality, Cabelli [4] considered that the ideal indicator should have the following characteristics :

- it should be consistently and exclusively associated with the source of pathogens
- it must be present in sufficient numbers to provide an accurate density estimate whenever the level of each of the pathogens is such that the risk of illness is unacceptable.
- the resistance of the indicator to wastewater treatment processes, disinfectants, and environmental stress should approach that of the pathogens.
- the indicator should be quantifiable in recreational waters by reasonably facile and inexpensive methods and with considerable accuracy, precision, and specificity.

The first bacterial indicator used for recreational water was total coliform (TC). The TC guideline of 1000/100 ml was established in 1933 based on the recommendation of the American Public Health Association and the State Sanitary Engineers Committee [5]. The TC group includes *E. coli*, *Klebsiella* sp., and *Citrobacter* sp.. However, several of these species are found in soils, industrial wastes, and natural waters, and do not necessarily connect with fecal contamination. The lack of evidence relating the TC level and transmission of infectious disease during contact recreational activities in water indicated that TC was not an acceptable bacterial indicator of recreational water quality. Therefore, it was gradually replaced by the fecal coliform (FC) guideline of 200/100 ml, which was recommended in 1968 by the National Technical Advisory Committee (NTAC) to the Federal Water Pollution Control Administration [6]. The FC guideline is currently recommended by the USEPA and has already been adopted by most states in the U.S. for their recreational waters [7]. Both TC and FC have also been used in Hong Kong for the monitoring of bacterial water quality at beaches, around submarine outfalls and seawall outfalls, and in typhoon shelters [8].

Fecal coliform, mainly composed of *E. coli* and *Klebsiella* sp., is more directly related to fecal contamination by warm-blooded animals than is total coliform. However, it has recently been reported that *Klesiella* sp. can also be found in rather large numbers in industrial wastes containing high concentrations of carbohydrates [9, 10]. These findings suggest that situations may arise where a high FC level is present in a non-fecal contaminated water which is receiving a carbohydrate rich industrial effluent. As the presence of *Klebsiella* sp., evaluated as FC, may not relate to fecal contamination, it can be argued that *E. coli* alone can be a more accurate bacterial indicator of fecal contamination than FC. In fact, *E.coli* has been adopted by the World Health Organisation Regional Office for Europe as the bacterial indicator of recreational water quality for many years [11]. It is also now recommended as the bacterial water quality parameter for beach water in Hong Kong.

The escalating demand for high quality recreational waters in the 1970's and the limitations of FC as a satisfactorily bacterial indicator of recreational water quality has promoted further research in this area. The USEPA has conducted an extensive search for the best indicator of recreational water quality based on epidemiological-microbiological studies [7]. The results of the studies did confirm that *E. coli* is a better indicator than FC for recreational water quality. However, *E. coli* is not the best indicator among the bacterial indicators investigated. The level of *Enterococci* in the bathing water has the highest correlation with the rate of swimming-associated gastrointestinal diseases. This finding will lead to further research work on using *Enterococci* as the bacterial indicator of recreational water quality.

Significance of Seawater Bacterial Decay Rate in Outfall Design

A marine sewage outfall is typically a long pipeline with diffusers at the front end for transporting the treated sewage some distance from the shore and discharging the effluent to the seawater without causing detrimental effect to the marine environment. Whether the discharge of the effluent creates an unacceptable water quality situation in the receiving waters is usually judged by predeter-

TABLE 1 [from Pearson(1)]

Comparison of Computed Outfall Lengths for

Variations in Eddy Diffusivity and Decay

Eddy diffusivity ft^2/sec	T_{90} hr	Computed outfall length ft
50	1	4,470
500	1	3,670
50	4	16,300
50	10	26,700
500	10	18,000

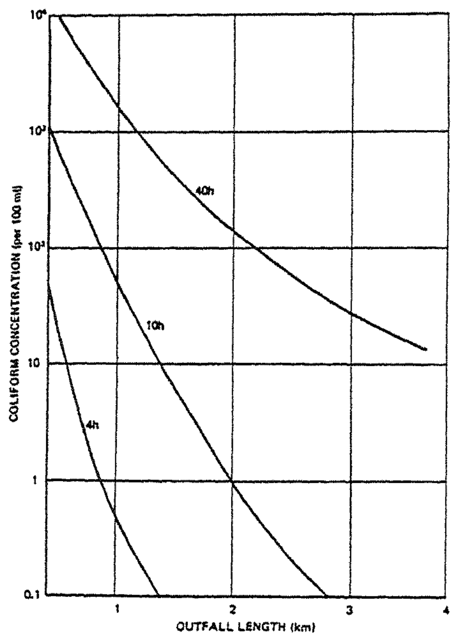

Fig. 1 Relation between predicted coliform concentration and outfall length for T_{90} values of 4, 10 and 40 hrs [Source : WRc (13)]

mined water quality standards. As discussed in the previous section, the setting of water quality objectives and standards is a very difficult task. Assuming that a bacterial water quality standard of 200/100 ml *E. coli* has been set for recreational use of receiving waters, the question related to marine outfall design is how far from the shore should diffusers of the outfall be placed so that the discharge will not violate the specified water quality standard.

The major natural processes that tend to reduce the concentration of a conservative pollutant in the effluent to acceptable levels in the receiving water are initial dilution and eddy diffusion. A large amount of research has been conducted to determine the role of these two processes in reducing the pollution level of receiving waters. A general review of the subject was presented by Grace in his text on marine outfall systems [12]. When evaluating the levels of non-conservative pollutants in receiving waters, their decay rates should also be considered. The decay rates of *E. coli* and other microorganisms in the receiving waters are commonly represented by T_{90} which represents the time required for a 90% reduction in their concentrations. Therefore the concentrations of non-conservative pollutants, such as *E. coli*, in receiving waters are not only dependent on the initial dilution and eddy diffusion but also on their decay rates (T_{90}) in a particular environment.

The relative importance of eddy diffusivity and the bacterial decay rate in determining the length of outfall has been shown by Pearson [1]. Under the same conditions of discharge, mixing depth, and current velocity, the required outfall lengths to obtain the same total dilution at different eddy diffusivity and T_{90} were calculated (Table 1). In this case, the T_{90} has a greater influence than the eddy diffusivity in the outfall design.

In the United Kingdom., the relation between predicted coliform concentration and outfall length for different T_{90} values has also been considered by the Water Research Centre in compliance with bacterial standards for bathing beaches (fig.l) [13].

The significance of T_{90} in determining the outfall length is further amplified by the great variability in the T_{90} values. The magnitude of the reported T_{90} values ranged from less than 0.5 hr. to more than 20 hrs. [14]. Reviewing the application of the coliform, fecal coliform and *E. coli* T_{90} values in seawater for marine sewage outfall design, Grace [12] pointed out that the very great variability in T_{90} values may render of limited value a vast expenditure of effort in assessing the physical dilutions of effluents in receiving waters.

Bacterial Decay Rates in Seawater

Although the factors affecting the survival of enteric bacteria in seawater are not fully understood, the bacterial decay rates in seawater have already been extensively used in marine outfall design. This topic was reviewed by Greenberg [15], Mitchell [16], Mitchell and Chamberbin [17], and Gameson and Gould [18], and the factors considered by the investigators included sedimentation, predation, pH, salinity, solar radiation, algal and bacterial toxins, bacteriophages, temperature, and nutrients deficiencies. Among these factors, the effect of solar radiation on bacterial decay has received more attention in recent years [19, 20, 21, 22, 23, 24] and has been proposed as the most important factor for the bacterial decay in seawater [14].

Mitchell and Chamberlin [14] have developed a bacterial decay model based on the effect of solar radiation alone. However, the application of this model is very limited. Most of the recent studies in this area still support the theory that light is an important factor for bacterial decay in seawater, but Lessard and Sieburth [21] show that bacterial decay rates in seawater were not correlated with light intensity, but significantly correlated with water temperature. The results of their study also showed that bacterial decay in seawater may be affected by some factors interacting with each others.

Bacterial decay rates are required in both scientific research on factors affecting bacterial decay and engineering practice for determining the lengths of marine outfall. There were two distinct methods of measurement, the *in-situ* experiment and the shore-based experiment. Most of the early bacterial decay studies were confined to simple shore-based beaker type batch experiments. At the other extreme is the expensive *in-situ* tracer study. Between these extremes are methods using closed containers such as bottles [25], polyethylene bags [26], or dialysis tubings [27] submersed in water. Recently, diffusion chambers have been constructed and used in the field for measurement of bacterial decay rates [24, 28, 29]. It was found that the diffusion chamber was a better approach than the batch experiment for bacterial decay studies and the decay rates obtained by the diffusion chamber method and the batch experiment differed significantly.

Conclusions

The following conclusions were drawn based on the above information on bacterial decay in seawater:

(i) bacterial water quality standard of receiving waters is, in general, the guideline for determining the length of marine outfall;

ii) the bacterial decay rate is a very sensitive parameter in calculating the lengths of marine outfall;
iii) there are great variabilities in bacterial decay rates, even at the same location at different time of the year;
iv) the factors affecting the bacterial decay rates in seawater are not fully understood, but solar radiation has recently been accepted as an important factor;
v) recent studies have shown that the factors affecting bacterial decay in seawater interact with each other;
vi) there are two distinct methods to measure bacterial decay rates. The *in-situ* tracer method is too expensive and also subject to seasonal variations. However, a satisfactory shore-based method has not yet been developed. The diffusion chamber method is considered to be the best available shore-based method currently under development.

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Treatment of Wastewater from Small and Medium-Sized Bleaching and Dyeing Factories

Henry Chiu, K.L.Tsang & Raymond M.L. Lee

Introduction

The bleaching and dyeing industry is essential to the textile industry, which has retained a predominant position in Hong Kong's economy for many years. Up to the third quarter of 1986, there were about 384 bleaching and dyeing factories in Hong Kong. Over 89 per cent of them are small and medium sized factories, each with fewer than 100 employees (Reference 1). One distinct characteristic of the bleaching and dyeing operation is the large quantity of water used in its production process. In comparison with other effluent-generating industries such as electroplating, the amount of water required in the bleaching and dyeing processes is three to seven times greater. Table 1 lists the average water consumption figures for typical bleaching and dyeing, and electroplating factories in Hong Kong.

With increasing concern about environmental protection, it may no longer be acceptable for the bleachers and dyers to discharge their effluents into receiving water-bodies without treatment. Various issues concerning the treatment of bleaching and dyeing wastewater are briefly discussed in this paper.

Manufacturing Processes

The fibres handled by the bleaching and dyeing industry range from cotton, wool and silk to synthetic fibres. Each type of fibre, depending on the specifications of the customers, can be processed in a number of ways. Because of the complexity and great variation of the bleaching and dyeing processes, it is not practical to describe all that are practised locally. Instead, only those most commonly used will be discussed. For textile goods these are:

Desizing

Before the weaving of fibres such as cotton, the thread is often passed through a starch solution and then dried, to give it the strength and stiffness to withstand the abrasion and friction generated in weaving. Before bleaching and dyeing, the layer of starch has to be removed from the fabric to expose the surface for the process chemicals. Desizing is carried out by soaking the fabric in a hot-water bath containing an enzyme, which gradually removes the starch by hydrolytic action. The desized cloth is then rinsed in hot water.

Scouring

In this process, the wax and grease contained in the fibre are removed in order to enhance the up-take of dye. Caustic soda, sodium carbonate and soap are the main cleansing agents used.

Bleaching

When fabric has to be dyed a very light colour, it has to be bleached beforehand. The common bleaching agents are chlorine, hypochlorite and hydrogen peroxide.

Dyeing

This is the process in which desired colour is imparted to the fabric by the use of dye. A great variety of dyes are available but the majority of those used in the industry are organic chemicals. In essence, the colours of the dye chemicals are derived from the presence of chromogens, made up of unsaturated functional groups such as:-

$>C=C<$	Ethylene linkage
$>C=N-$	Carbim group
$>C=O$	Carbonyl group
$-N\begin{smallmatrix} \nearrow O \\ \searrow O \end{smallmatrix}$	Nitro group
$-N=N-$	Azo group
$>C=S$	Thiocarbonyl group
$-N=O$	Nitroso group, etc.

Depending on their chemical nature, the different types of dye chemicals can also be classified as follows:-

- Direct dye
- Acid dye
- Vat dye
- Sulphur dye
- Disperse dye
- Reactive dye

The above is only a brief description of the processes which in practice will vary from factory to factory. In addition, it should be noted that not all of these processes will be carried out in sequence. Depending on the nature of fabric and the quality of the end-product required, some processes such as bleaching can be omitted. For illustration, typical work flow sheets for bleaching and dyeing of woven cotton, knitted cotton and silk cloth are shown in Figures 1-3.

The Wastewater Characteristics

The characteristics of the wastewater discharged from a bleaching and dyeing factory are dependent on the types of fabric being treated as well as the processes used. It is therefore not possible to estimate the characteristics of the wastewater from one factory by using the data of another. The actual characteristics have to be established through sampling and laboratory analysis of the wastewater concerned.

In general, bleaching and dyeing wastewater is highly coloured, usually alkaline and with substantial suspended solids (SS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Analyses of wastewaters obtained in a survey by the Hong Kong Productivity Council (HKPC) at a number of local bleaching and dyeing factories are shown in Tables 2-5.

High BOD and COD values are found in the effluent from desizing and neutralisation, because both the starch sizing agent and the acetic acid used for neutralisation are organic substances which can contribute to this. It is estimated that, for every 100 g of starch in wastewater, the resulting BOD loading will be increased by 46g and for every 100g of acetic acid by 62g.

Treatment of Bleaching and Dyeing Effluent

Depending on the discharge requirements, any bleaching and/or dyeing effluent will have to be treated to a greater or lesser extent. In this section, the process for the following most common parameters requiring treatment are discussed:-

- pH adjustment
- Colour removal
- Organics removal

pH adjustment

In general, the pH of the bleaching and dyeing effluent is alkaline (pH 10-12). This may be adjusted either by the addition of sulphuric acid or the use of flue gas.

Using sulphuric acid, expensive capital equipment is not required. The caustic soda in the waste is neutralised to form a neutral salt:

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

To ascertain the quantity of acid required for a specific waste it is necessary to determine the appropriate titration curve. Figure 4 shows a typical curve established by HKPC for a small factory with 20 workers and producing $100m^3$/day wastewater. It is evident that the quantity of sulphuric acid needed by this factory for pH adjustment is about 0.014 tonne/day which, at the current price of $1500 per tonne, will cost $21/day.

This chemical cost can be reduced if the boiler flue-gas is used for neutralisation. Well-burned stack gases contain approximately 14% CO_2. If this is dissolved in the waste-water, it will form carbonic acid, a weak acid, which will react with the wastes and neutralise the excess alkalinity as follows:-

$$CO_2 + H_2O \rightarrow H_2CO_3 \text{ (Carbonic acid)}$$

$$H_2CO_3 + 2NaOH \rightarrow Na_2CO_3 \text{ (Sodium carbonate)} + H_2O$$

$$H_2CO_3 + Na_2CO_3 \rightarrow 2NaHCO_3 \text{ (Sodium bicarbonate)} + H_2O$$

Typical systems for flue gas neutralisation are shown in Figures 5 & 6. However, it should be noted that the capital investment for the flue gas neutralisation system will be higher than the sulphuric acid neutralisation system, so the flue gas system may be more appropriate and attractive to large factories with large effluent outputs.

The addition of neutralising chemicals can be accomplished automatically through the use of a pH control system. Such as system consists essentially of a pH detecting device and a controlling circuit which can activate or de-activate the chemical dosing pumps. The most commonly used pH detecting device is a glass electrode used in conjunction with a reference electrode. A typical glass electrode for this purpose is shown in Figure 7. It has a specially formulated glass membrane tip which is virtually specific for measurement of the hydrogen ion activity. It also has a sealed internal, with a buffered solution containing chloride ion, and the internal circuit is completed with a reference electrode. This internal reference electrode may either use the saturated calomel (Hg/Hg_2Cl_2) or silver/silver chloride ($Ag/AgC1$).

In using the glass electrode for pH detection, the following precautions should be taken:

Table I
Average water consumption of Hong Kong factories engaged in bleaching & dyeing and in electroplating (Reference 2)

Nos of Employees \ Type of factory	Bleaching & Dyeing (m^3/day)	Electroplating (m^3/day)
1 – 9	46	7
10 – 19	68	15
20 – 49	177	28
50 – 99	564	159
100 –199	1110	395

Table 2
Analyses of effluents from bleaching and dyeing of woven cotton (HKPC data)

Process	Volume of Discharge (m^3/ 1000kg)	pH	BOD (mg/ℓ)	BOD Loading (kg/ 1000kg)	COD (mg/ℓ)	COD Loading (kg/ 1000kg)	SS (mg/ℓ)	SS Loading (kg/ 1000kg)
Desizing	50–59	4.5–7.2	709–1220	35.5–72.0	2460–3540	123–209	174–682	8.70–40.2
Scouring and Bleaching	50–59	8.6–12.5	170–549	8.50–32.4	777–3100	38.9–183	114–920	5.70–54.3
Dyeing (Sulphur Dye)	50–59	10.8–13.0	333–945	16.7–55.8	1230–6430	61.5–379	85–1610	4.25–95.0
Dyeing (Direct Dye)	50–59	7.2–9.3	46–1160	2.30–68.4	840–2310	42.0–136	27–140	1.35–8.24
Oxidation	50–59	3.5–4.8	940–1650	47.0–97.4	2830–3350	142–198	196–400	9.80–23.6

Note: The chromium concentrations found in the oxidation process range from 47–225mg/ℓ

Table 3

Analyses of effluents from bleaching and dyeing of knitted cotton (or the cotton fraction of cotton-synthetic fibre mixed fabrics) (HKPC data)

Process	Volume of Discharge (m^3/ 1000kg)	pH	BOD (mg/ℓ)	BOD Loading (kg/ 1000kg)	COD (mg/ℓ)	COD Loading (kg/ 1000kg)	SS (mg/ℓ)	SS Loading (kg/ 1000kg)
Scouring and Bleaching	47–53	9.6–12.9	9–420	0.42–30.7	117–3430	5.50–250	9–474	0.42–34.6
Neutralization	18–36	3.7–4.0	197–2200	3.55–79.2	1790–8550	32.2–308	99–1830	1.78–65.9
Dyeing (Reactive Dye)	55–91	8.4–11.3	5–396	0.28–36.0	231–2500	12.7–228	35–662	1.93–60.2

Table 4

Analyses of effluents from dyeing of synthetic fibres (HKPC data)

Process	Volume of Discharge (m^3/ 1000kg)	pH	BOD (mg/ℓ)	BOD Loading (kg/ 1000kg)	COD (mg/ℓ)	COD Loading (kg/ 1000kg)	SS (mg/ℓ)	SS Loading (kg/ 1000kg)
Desizing	55–73	3.3–8.3	17–302	0.94–22.0	289–2550	15.9–186	4–144	0.22–8.32
Reduction Clearing	36–55	9.4–12.3	53–1005	1.91–55.3	1130–5420	40.7–298	16–249	0.58–137

Table 5

Analyses of effluents from bleaching and dyeing of silk cloth (HKPC data)

Process	Volume of Discharge (m^3/ 1000kg)	pH	BOD (mg/ℓ)	BOD Loading (kg/ 1000kg)	COD (mg/ℓ)	COD Loading (kg/ 1000kg)	SS (mg/ℓ)	SS Loading (kg/ 1000kg)
Scouring and Bleaching	6.5–7.8	7.3–9.9	29–906	0.2–7.1	112–4790	0.7–37.4	7–496	0.04–3.87
Dyeing	6.5–7.8	5.9–9.9	19–938	0.1–7.3	131–7490	0.9–58.4	5–412	0.03–3.21
Treatment with Acetic Acid	4.4–5.2	3–3.5	85–155	0.4–1.8	1420–5560	6.3–28.9	24–30	0.1–0.2

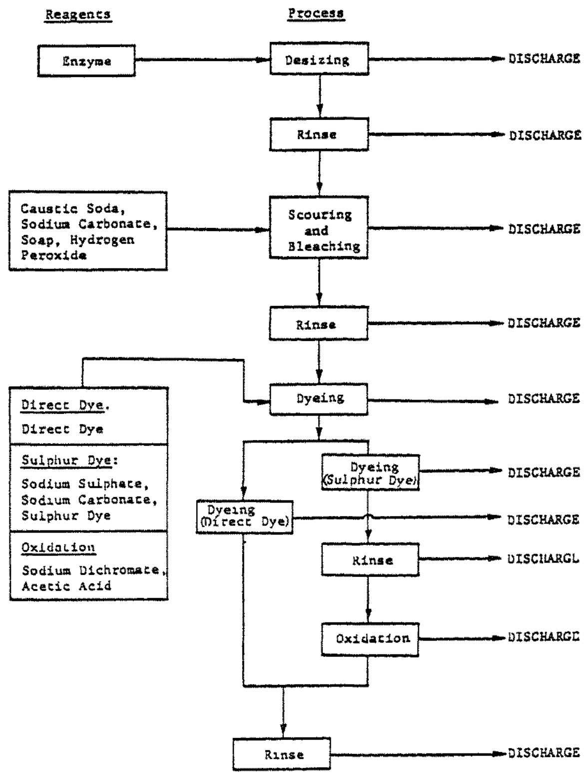

Fig.1 Bleaching and dyeing processes for woven cotton

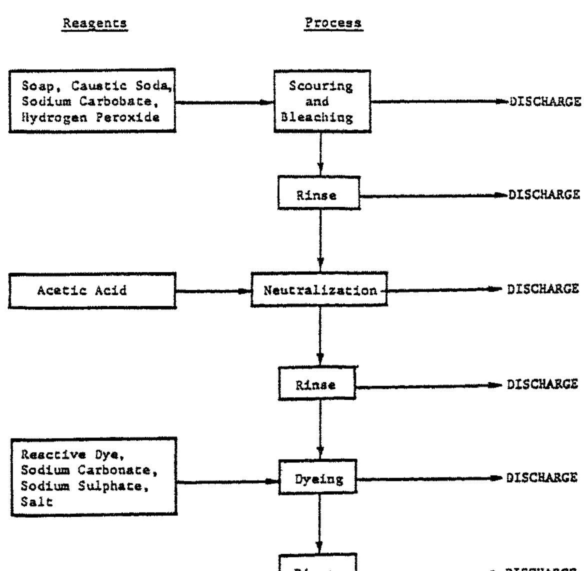

Fig.2 Bleaching and dyeing processes for knitted cotton

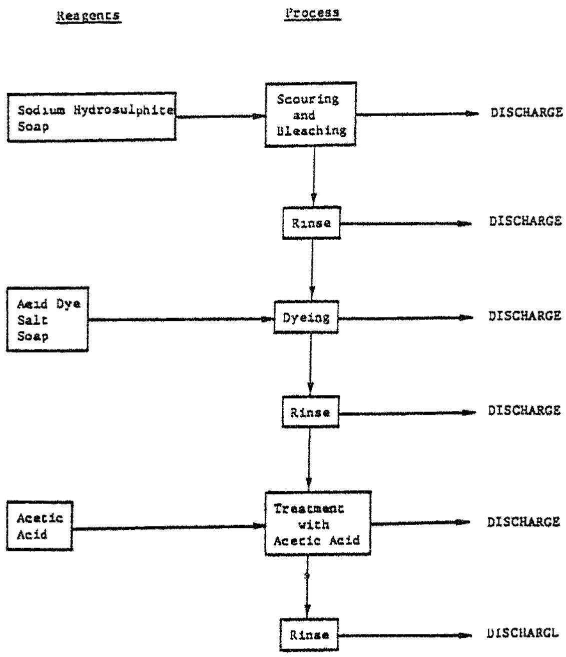

Fig.3 Bleaching and dyeing processes for silk cloth

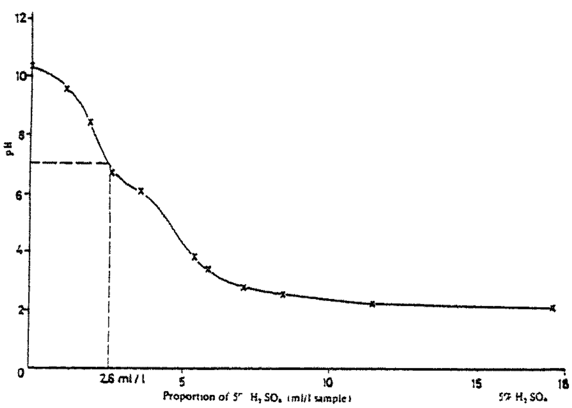

Fig.4 Filtration curve for a small bleaching and dyeing factory (1000 ml sample)

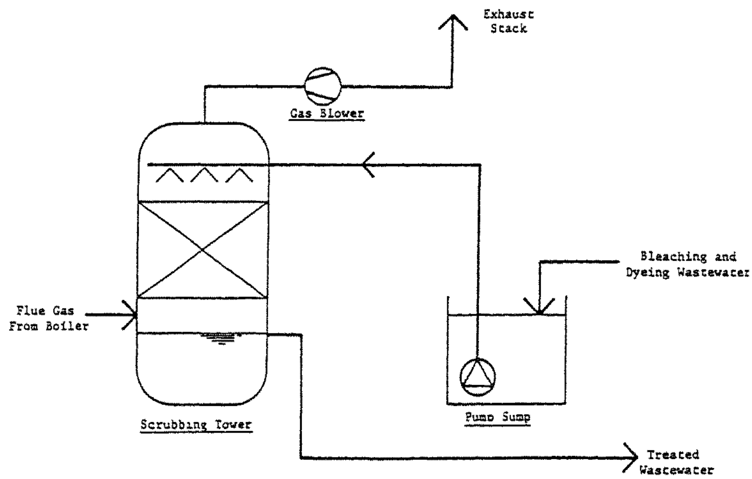

Fig.5 A typical system using flue gas neutralisation (System type 1)

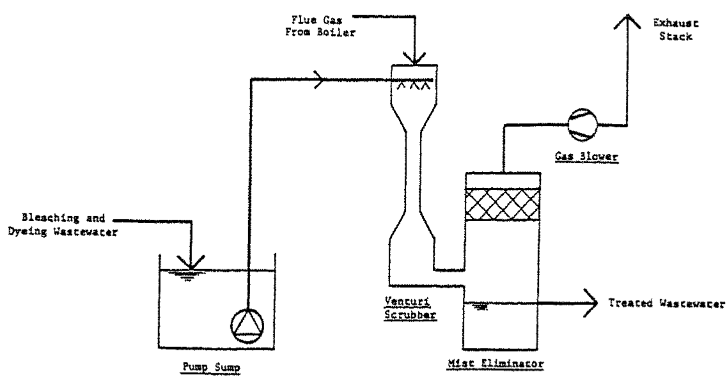

Fig.6 A typical system using flue gas neutralisation (System type 2)

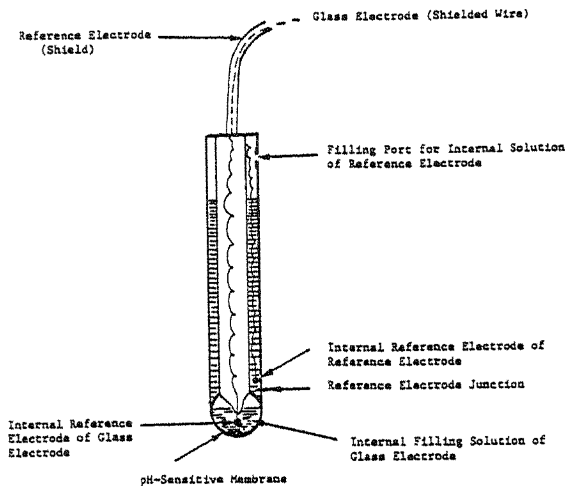

Fig.7 A typical combination glass electrode

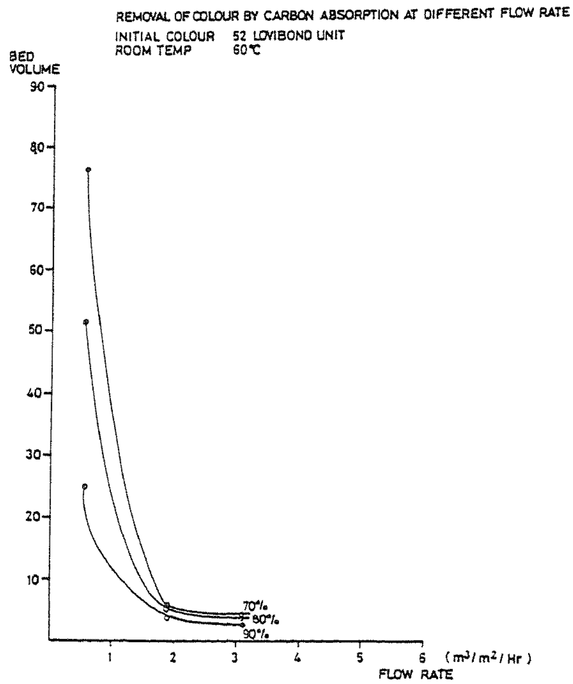

Fig.8 Variation of adsorption capacity with surface flow-rate

Table 6
Colour removal by use of chlorine (Reference 3)

Type of dye		Dosage (mg/l)	Colour removal (%)
Disperse Dye	DB	440	92
	PV	880	73
	RR	880	97
	SY	880	87
Acid Dye	NAR	66	45
	VFB	22	90
	MBB	44	96
	SNY	11	97
	PY	13	88

Table 7
Colour removal by use of ozone (Reference 3)

Type of dye waste	pH	T (°C)	% Colour removal
Acid	2.5	20	98
Disperse	7.3	60	92
Direct	7.1	45	95
Reactive	11 2	20	93

Table 8
Jar tests on colour removal by chemical coagulation/flocculation (Reference 4)

Type or Coagulant	Indigo Dyeing Wastewater		Sulphur Dyeing Wastewater		Combined Dyeing Wastewater	
	Dosage (mg/ℓ)	% Removal	Dosage (mg/ℓ)	% Removal	Dosage (mg/ℓ)	% Removal
$A\ell_2(SO_4)_3 \cdot 18H_2O$	33000 ($A\ell^{+3}$) (pH adj to 5 5)	88 5	30000 ($A\ell^{+3}$) (pH adj. to 5.5)	99.4	600 ($A\ell^{+3}$) (pH adj. to 5.5)	97.6
$A\ell_2(SO_4)_3$ $18H_2O$ + $Ca(OH)_2$	25000 ($A\ell^{+3}$) + 5300	91.5	30000 ($A\ell^{+3}$) + 110000	98.8	40 ($A\ell^{+3}$) + 5000	97.5
$Ca(OH)_2$ + $FeSO_4 \cdot 7H_2O$	2500 + 7000	99.1	5000 + 10000	97.5	2600 + 5000	99.1
$FeC\ell_3$ $6H_2O$	4000	86.9	5000	93.3	380	0
$FeSO_4 \cdot 7H_2O$	30000	95.4	3500	95.3	2000	96.1

Table 9
Effect of variation of operating parameters on the performance of activated sludge process in treating bleaching and dyeing wastewater
(Reference 3)

Trial	MLSS (mg/ℓ)	Hydraulic Retention Time (hr)	Kg BOD/Kg MLSS/day (F/M)	COD (mg/ℓ)		BOD (mg/ℓ)		% Removal	
				Influent	Effluent	Influent	Effluent	COD	BOD
1	2000	7	1.37	2800	728	800	400	74	50
2	3200	12	0.50	2800	560	800	80	80	90
3	4400	36	0.12	2800	448	800	24	84	97
4	4000	74	0.06	2800	322	800	13	88.5	98.4

- Avoid installing pH sensors close to either the waste-water inlet or the point of chemical application to reduce the possibility of coating the sensor with the precipitates formed in the chemical reaction;
- In wastewater that contains high concentration of grease and oil use a pH sensor system that is fitted with an automatic cleaning device (such as an ultrasonic system);
- Install the pH sensors at locations where there will not be excessive velocity of flow, so as to reduce the abrasive damage that may be caused to the glass electrode;
- To minimise corrosion, never use the glass electrode in hot and alkaline solution (pH $\geq$ 12) or acidic solution ($\leq$ 3) containing fluoride salt.

Removal of colour

A substantial degree of colour reduction, depending on the types of dye present, can be achieved with the following methods:

- oxidation

The use of oxidising chemicals such as chlorine, sodium hypochlorite, calcium hypochlorite and ozone can reduce colour in the spent dye waste through the oxidation of the unsaturated chromogen functional groups of the dye molecules. However, this effect is pronounced only for dye molecules with straight-chain unsaturated chromogen groups. For dye molecules with aromatic unsaturated chromogen groups, the slowness of the oxidation effect renders its use impractical. The colour reduction achieved by the use of chlorine and ozone on a number of spent dye wastes is shown in Tables 6 & 7.

In practice, the actual colour removal achievable by an oxidising agent on a specific dyeing waste needs to be established by experiment.

- chemical coagulation followed by flocculation

Colour removal caused by chemical coagulation/flocculation is usually effected by the adsorption of dye molecules onto newly formed insoluble precipitates, thus removing them from the wastewater.

The common types of coagulant used for colour removal are alum ($Al_2(SO_4)_3 . 18H_2O$), ferrous sulphate ($FeSO_4$) and ferric chloride ($FeCl_3$). Under optimum pH and stirring conditions, these coagulants will hydrolyse to form insoluble hydroxide particles which adsorb and remove the dye molecules. The insoluble hydroxides thus formed are often of low density and not readily settleable. In order to improve its setting characteristics, flocculants have to be added which, with these coagulants should preferably be anionic polyelectrolyte. The polyelectrolyte molecule is essentially a long chain organic molecule which achieves its flocculation affect by attachment onto the surface of the hydroxide particles at one or more sites, while a significant length of the polyelectrolyte extends into the bulk solution. When two of such particles are attached, the extended polyelectrolyte molecule will agglomerate.

The typical range of colour removal efficiency of the various coagulants is shown in Table 8.

- activated carbon adsorption

Activated carbon is a general term which applies to any amorphous form of carbon that has been specially treated to give high adsorption capacities. Typical raw materials include coal, wood, coconut shells, and petroleum base residues etc. High adsorption capacitiès are generated by the combustion of the raw materials at a high temperature in an oxygen-starved atmosphere. This material has a high capacity for adsorption due primarily to the large surface area available, 500-1500 m^2/g, resulting from a large number of internal pores. Adsorption on activated carbon occurs when a dye molecule is brought up to its surface and held there by physical and/or chemical forces.

It is common to use granular activated carbon in form of a bed like a sand filter through which the coloured waste is passed. Dye molecules are attracted by the carbon and adsorbed on its surface. When the carbon becomes loaded with adsorbed molecules and loses its adsorptive ability, it is removed from the system or regenerated.

In using an activated carbon system, the adsorptive capacity available is dependent on surface flow rate of wastewater used as shown in Figure 8.

Removal of organics

Removal of organics is usually acheived by using biological oxidation of the waste under aerobic conditions. In this reaction, the organics contained in the bleaching and dyeing wastewater will be utilised by the micro-organism as sources of energy.

$$C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_20$$

In order to ensure the aerobic biological oxidation processes can be carried out properly, the following operational aspects have to be observed:-

- Adequate oxygen has to be supplied to the wastewater to ensure that the dissolved oxygen level is not less than 1 mg/l;

- Appropriate amounts of nutrients, mainly nitrogen and phosphous, have to be added to the wastewater to ensure the proper growth of micro-organism. Desirable quantities can be estimated from the following ratio:

  BOD(removed) : N : P = 100 : 5:1
- The pH of the wastewater is preferably kept between 7 and 9;
- The temperature of the wastewater needs to be maintained below 40^0C.

Biological oxidation can be carried out by different processes, the most common ones being:

- activated sludge

In the activated sludge process, the bleaching and dyeing wastewater is stabilised biologically in an aeration basin under aerobic conditions. The aerobic environment is achieved by the use of diffused air of mechanical aeration. The reactor contents are referred to as the mixed liquor (ML). After the waste is treated in the reactor, the resulting biological mass is separated from the liquid in a settling tank. A portion of the settled biological solids is recycled, the remaining mass is wasted and dewatered before disposal. The concentration at which the biological mass should be kept (MLSS), the hydraulic retention time of the wastewater in the aeration basin and the quantity of organics that can be removed by unit mass of biological solids are the critical design factors to determine the efficiency of the system. Table 9 shows the results of some tests of the effect of removal of organics with varying operating parameters.

- trickling filter

A trickling filter consists of a bed of highly permeable media to which micro-organisms are attached. During operation, the wastewater is sprinkled over the filter media and allowed to trickle through the bed. The filter media are usually built of plastic cells or leaves and can be erected to depths of 9-12 m. The filter is usually circular and the wastewater is distributed over the top of the bed by a rotary distributor. Each filter has an underdrain system for collecting the treated waste and any biological solids that have become detached from the media. This underdrain system is important both as a collecting unit and as a porous structure through which air can circulate.

- Biodisc

The biodisc unit consists of a series of flat, parallel discs which are rotated while partially immersed in the waste being treated. Biological slime covers the surface of the disc and both adsorbs and absorbs collodial and dissolved organic matter present in the waste water. Excess slime generated by synthesis of the waste materials is sloughed off gradually into the waste water. Thus, the rotating discs provide:-

(1) mechanical support for a captive, microbial population;

(2) a mechanism of aeration;

(3) contact between the biological slime and the waste-water.

Use of closely parallel discs achieves a high concentration of active biological surface area and therefore of active organisms. Adjustment of the rotational speed of the discs gives simultaneous adjustment of the rate of aeration and intensity of contact which enables this process to give effective treatment to highly concentrated wastes. Because negligible head loss is encountered through the system the power requirement for this process is very low. Its simplicity of construction and operation has demonstrated that minimal unskilled maintenance is all that is required for efficient operation.

A number of alternative treatment methods are available for treating bleaching and dyeing wastewater. However, the effect of treatment will vary with the specific chemical nature of the wastewater from a particular factory. In order to obtain the optimum design for minimum cost of treatment, it is necessary to establish the efficiency of individual treatment units by pilot-scale treatability studies.

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Mathematical and Experimental Modelling of Some Environmental Problems

Joseph H.W. Lee, A.W. Jayawardena and K.T. Chan

Introduction

Since the inception of the environmental engineering curriculum within the Civil Engineering Department of the University of Hong Kong in 1979, a number of research studies related to water pollution have been carried out: fluid mechanics of wastewater disposal, mathematical modelling of tidal circulation and far-field pollutant transport, water quality modelling, longitudinal dispersion in natural stream and porous media, stochastic modelling, and modelling of denitrification in the activated sludge process. In this paper the nature of and the motivation behind this research are described, using wherever possible Hong Kong examples for illustration. The implications of the relevant findings are discussed, along with our perception of research needs and ongoing research directions. References to further specialised technical details are given at the end of the paper.

It is generally accepted that unless the effects of water pollution can be predicted/quantified satisfactorily, it is not possible to manage our environment effectively. Consequently it is not surprising that the research described herein is devoted to understanding the physical processes that govern the mixing and transport of pollutants in the water environment and quantitative modelling of an important biological treatment process. A sound understanding based on both theoretical and experimental modelling work can be gainfully used in the control of water pollution.

Fluid Mechanics of Wastewater Disposal

Mixing of a round buoyant jet

To control local pollution conditions to acceptable levels, sewage or thermal effluent is often discharged in the form of a number of submerged buoyant jets at the bottom of the ocean or coastal water. Figure 1a shows a 1:11 undistorted scale hydraulic model of a single-port section of the submerged multiport sewage diffuser serving Wah Fu Screening Plant. By preserving densimetric Froude similitude and ensuring a jet Reynolds number in excess of 2000, the dominant turbulent mixing processes of the buoyant jet can be modelled. It can be seen that the turbulent round jet, inclined at 20^{0} to the horizontal, spreads linearly near the discharge, but curves rapidly upwards when the initial jet kinetic energy is dissipated and buoyancy forces become dominant. The momentum and buoyancy-induced entrainment cause the mixing of the wastewater with the uncontaminated surrounding fluid; the wastewater is thereby diluted. The degree of dilution (or the resulting pollutant concentration) in stagnant ambient water, of the order of 100 for many outfalls, can be predicted reliably using mathematical models founded on rigorous fluid mechanical princples (eg the model by Fan and Brooks used in local design). Integral jet models are typically based on either a constant jet spreading angle or an entrainment hypothesis for turbulent closure. Figure 1b shows a comparision of predicted vs measured centerline dilution for different depths in the Wah Fu study. Fresh water, with 600 ppm sodium chloride added as a tracer, is injected into sugar solution that simulates the same relative densities as between effluent and ambient sea water. In general the initial dilution, inferred from the measured tracer concentration, can be predicted to within 10 per cent; the discrepancy usually increases for larger dilutions, when the relative experimental error is also larger. The observed trajectory and width of the buoyant plume are also in excellent agreement with the theory.

In predicting the minimum surface dilution, account must be taken of the thickness of the surface layer within which there is little dilution additional to that attained up to the base of the field. (Lee & Jirka, 1981). For many problems, the dependence of the entrainment coefficient on the local densimetric Froude number should also be incorporated in a numerical calculation. Further, a general integral jet model can be developed to handle a row of arbitrarily inclined and spaced round jets, including the merging of the buoyant plumes at some distances above the discharge and the subsequent essentially two-dimensional vertically rising curtain of sewage. Figure 2 shows for example a calculation for the Kwun Tong outfall - both the jet width and centerline dilution calculated by such an approach is lower than that calculated by assuming no interference between adjacent jets. These calcualtions provide useful estimates for outfall design. The applicability of this type of model for thermal effluents in shallow depths has also been discussed (Lee *et al*, 1981).

Limited in-situ measurements of initial dilution at the Wah Fu outfall were also carried out. On February 11, 1982, a survey was carried out from the government vessel Chop Yat, with the assistance of the then Public Works Department. During the survey, the current strength registered was 0.15 m/s almost parallel to the shoreline. Temperature and salinity measurements were practically uniform over the depth. With some effort two sewage boils were clearly identified from a dinghy; a total of forty 500 ml samples were taken at various depths at and around the sewage boil and upstream and downstream of the outfall. Concurrently, samples were taken from the sewage effluent in the twin grit channels inside the screening plant; the sewage flow can be determined from the recorded depths in the grit channels. The sampling was completed within about half an hour, and all the samples were brought back to the laboratory and analysed for 5-day Biological Oxygen Demand (BOD_5), total coliform bacteria counts, and suspended solids concentration using standard methods. The minimum and average dilution inferred from the BOD data were 46 and 72 respectively, somewhat higher than the calculated still-water dilution based on a computed variation of discharge along the 43m diffuser. Such sketchy information, which confirms that high initial dilutions can be achieved in the field, is the most that can be expected from a survey with limited resources. However, with hindsight, the survey could have been converted into a much more useful exercise had the flow rate from the port been measured directly (for example, using an electromagnetic flow meter with diver assistance) and a dye tracer been used. It is our view that a few intensive surveys, similar to those carried out in England in recent years (Bennett, 1981), could be planned and carried out profitably at local sea outfalls at moderate cost. The point is that the type of data available in large quantities from routine monitoring, while useful for checking general conditions, can rarely be used for an evaluation of outfall performance - or, for that matter, of any mathematical model prediction. On the other hand, a field survey planned in conjunction with a mathematical model can go a long way in understanding the field performance of outfalls and water quality control in general, with a view of effecting better design and getting some clues to the answers to some important questions - eg the effect of tidal flushing on the initial dilution actually achieved in relatively enclosed waters like Tolo Harbour, or the mixing of a buoyant effluent in a relatively weak ambient current.

Initial dilution prediction in moving water

Whereas the initial dilution achieved by buoyant wastewater discharges in still water can be predicted reliably, there appears to be no universally accepted method of predicting initial dilution in moving water. In view of the fact that a tidal current is always present in many coastal locations, it is highly desirable to take into account the effect of an ambient current in outfall design. Primarily, the development of predictive methods has proceeded along two lines.

a) Correlation of field data or laboratory data of experiments designed to closely simulate prototype conditions. Equations for initial dilution have been proposed by Agg (1976), Bennett (1981) and White (1977); however, there is significant discrepancy among the various theories; predictions can differ by a factor from 3 to 10.

b) Development of relatively sophisticated mathematical models founded on fundamental fluid mechanics principles. Here the effort has not met with the same success as in the stagnant ambient case.

Both model development and verification have been hampered by the highly complicated flow geometry of a deflected turbulent buoyant jet in a cross current. Further, comparisons of laboratory data with theoretical predictions have been limited primarily to high-momentum discharges in weak currents. In view of these deficiencies, prediction of initial dilution in moving water has for some time been regarded as the weakest link in an outfall design.

The above discrepancies have been to a large extent resolved in a recent study (Lee *et al*, 1987) with the aid of mathematical models and a length scale analysis confirmed previously in a related study (Lee and Cheung, 1986). All available field and laboratory data of initial dilution in a moving current were successfully interpreted in a single framework by this new method of analysis. Simple equations for initial dilution prediction were arrived at; the results, endorsed by the Water Research Centre, show that significant increases in initial dilution can be obtained even in a weak ambient current. Figure 3 shows an example of the collective correlation of field data for plumes in a full current-dominated regime. Theoretical details of this new analysis can be found in Lee & Neville-Jones (1987a); the design implications and the statistical variability to be expected in the field have also been reported (Lee & Neville-Jones, 1987b). More detailed studies on the mechanics of a buoyant jet in a cross flow are currently under investigation. For a concise technical review of waste disposal in the ocean, the reader is referred to Lee & Jirka (1987).

Plane buoyant jet in stratified fluid

If the receiving water is stratified, the buoyant wastewater may entrain enough of the denser fluid in the lower layers that it never reaches the surface. Figure 4 is an example which depicts the mixing behaviour of a plane buoyant discharge in a linearly stratified fluid. The mixed buoyant effluent finds the level of its own density, overshoots a little, and finally settles to a submerged spreading layer. The submergence of the wastewater field presents certain advantages from the environmental point of view: surface recreation waters are protected; the wastewater effluent is subject to weaker wind-generated currents, and hence longer travel times before any pathogenic organisms are carried to nearshore areas of biological importance. In moderate to large depths with a stable stratification, this situation can be engineered to occur. Unlike round buoyant jets, there is scant

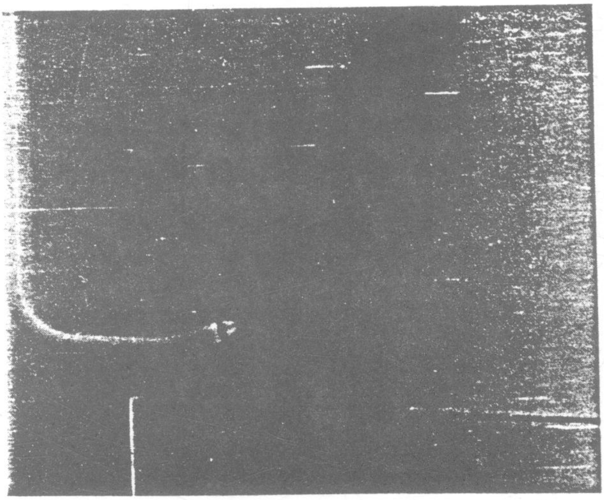


Fig.1 a) Buoyant jet effluent issuing from a 1:11 scale hydraulic model of the Wah Fu Sewage outfall. jet velocity = 0.74 m/s, jet diameter = 0.1 m, relative density difference = 0.014. Densimetric Froude number = 6.3

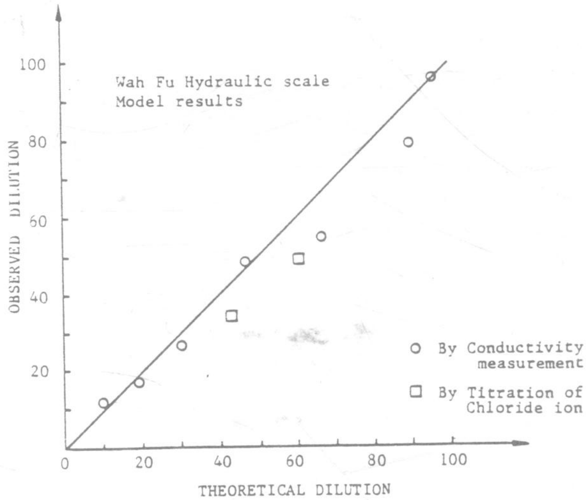


Fig.1 b) Comparison of theroetical prediction of minimum surface dilution with experimental data – Wah Fu model study.

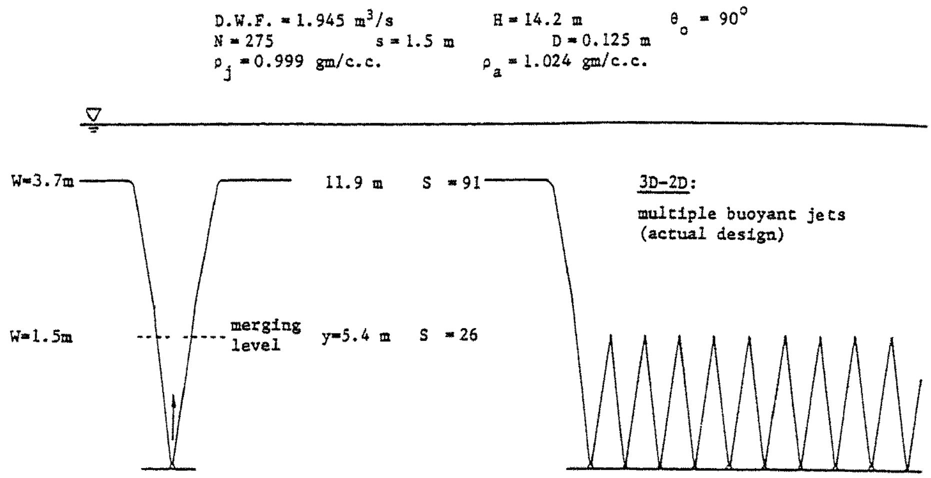


Fig 2 Computed results of a general integral jet model for the 256-port Kwun Tong submerged sewage diffuser Both the je width (W) and centerline dilution(S) at the level of plume merging and the base of the surface wastewater field ar shown

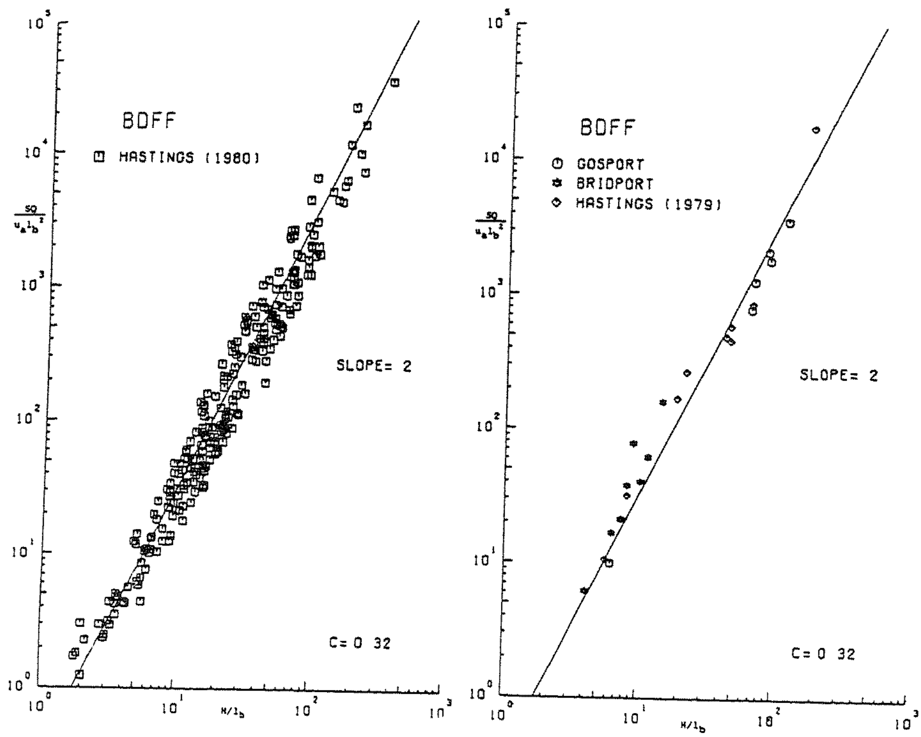


Fig 3 Correlation of in situ measurements of initial dilution in moving water at a number of sea outfalls in the United Kingdom Analysis is based on the use of length scales formed from the dynamic discharge momentum and buoyancy fluxes S is the minimum surface dilution measured in the sewage boil Q = discharge volume flux u_a = ambient current speed $l_b = B/u_a^3$ where $B = Q(\Delta\rho_j/\rho_a)g$ $\Delta\rho_j/\rho_a$ is the discharge relative density difference and g = gravitational acceleration

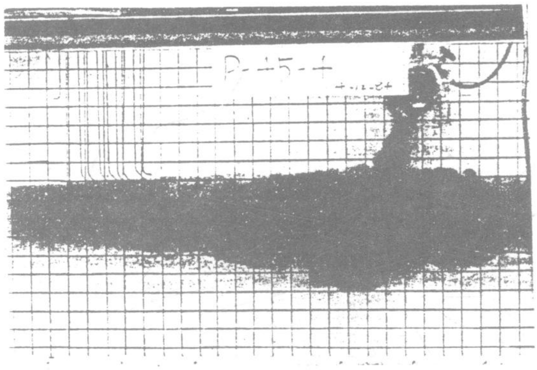


Fig.4 A plane buoyant jet in stratified fluid. Note the experiment is done with a negatively buoyant jet, so that the corresponding prototype situation is entirely upside down. Note also the thickness of the spreading layer.

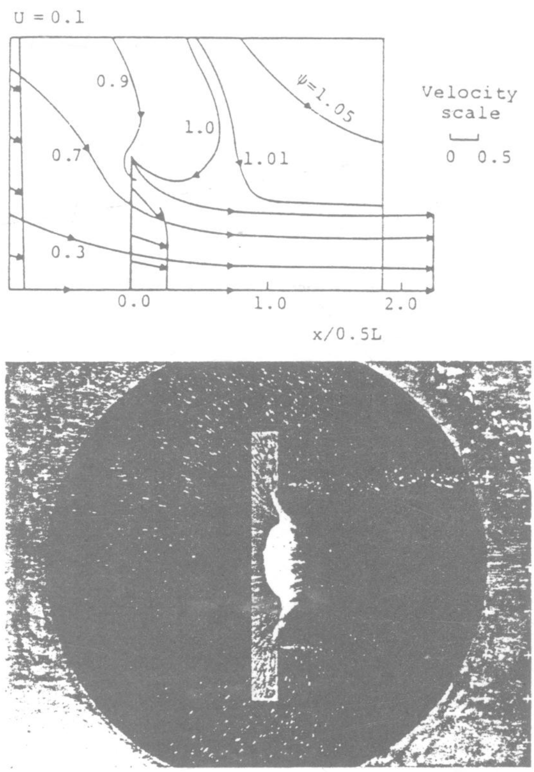


Fig.5 Computed and observed flow induced by a line of submerged shallow water jets in a weak co-flowing current. All the jets discharge in the same (+x) direction. a) computed streamlines for the upper symmetrical half of the flow field b) observed flow field made visible by paper chips: the length of the streaks indicate the relative magnitude of the velocities. Note the significant reverse flow in front of the multiple jet group even in a forward current.

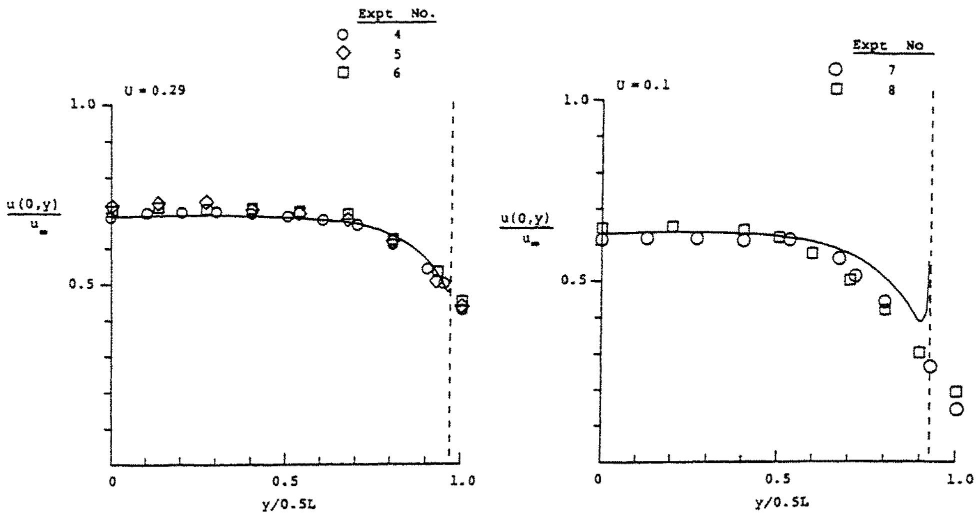


Fig 6 Comparison of predicted and measured point velocities in the multiple-jet induced flow for different ambient current ratios

Fig 7 a) Surface cooling water (CW) discharge from the 1500 MW Tsing Yi Power Station, New Territories The high velocity surface jet is plainly visible even at a distance

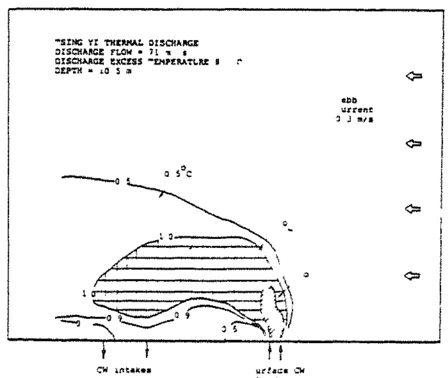


Fig 7 b) Experimental results in a 1:150 schematic physical model of the Tsing Yi thermal discharge Measured surface temperature field (isotherms refer to temperature excess in °C above the background temperature) in the vicinity of the power station in a relatively strong ebb current Note the plume attachment [hugging] to the downstream shoreline basic experimental data on the maximum height of rise of a plane buoyant jet (which simulates the wastewater effluent beyond the level of merging of the adjacent jets), and the distribution of concentration within the spreading layer. The experimental technique required for this delicate and elaborate experiment has been developed; the findings are detailed in Lee & Cheung (1986).

Multiple weakly-buoyant jets

Compared with sewage discharges, thermal effluents from once-through cooling systems of steam-electric power stations are characterised by much weaker buoyancy and much higher velocities. For a typical heated effluent with 8°C excess temperature, the buoyancy is about an order of magnitude less whilst the velocity is about an order of magnitude greater. Consequently, the near- field flow induced by such multiple submerged buoyant jets is primarily driven by the large momentum imparted to the receiving water; so entirely different predictive techniques from the ones described above have to be used. The mechanics of such a momentum-induced flow has been explained and computed by an exact inviscid vortex model (Lee & Greenberg, 1984). The basic theory has been verfied for different ambient currents and lateral boundary conditions by extensive experiments in a specially designed 11 x 6m shallow water basin in the Peel Laboratory of HKU. (Lee, 1985, Lee & Li, 1985) Figure 5 shows an example of a computed flow induced by the multiple-jet group in a co-flowing current, together with a flow visulaisation for the same condition in an experiment. The resemblance of the inwardly-directed flow character near the ends of the multiple jet group is evident. An example of comparison of observed point velocities with the theory is also shown in Figure 6. The theory has been extended to study the effect of a shoreline boundary on the mixing performance of such a water-quality-control device (Lee, 1984). A basic numerical and experimental investigation of the practical situation of multiple jets discharging in a perpendicular cross flow has recently been completed.

In contrast to submerged thermal discharges, condenser cooling water is often discharged through a surface or near-surface conduit at the coastline. Figure 7a shows such a heated surface discharge from the 1500 MW Tsing Yi power station. With a maximum cooling water (CW) flow of $71m^3/s$, the high velocity surface jet can entrain up to ten times its own flow within 200m from the discharge point; the ambient flow pattern is hence significantly modified by the discharge. A 1:150 schematic physical model was designed to examine the waste heat distribution in the vicinity of the thermal outfall. Figure 7b) shows the surfact excess temperature field in a steady ebb current of 0.3m/s. Supported by theoretical considerations and field measurements, it is seen that this high-momentum surface buoyant jet is attached to the downstream shoreline, with temperature rises in excess of 0.5°C around the intake area. The model has also been used to assess the thermal field and intake temperature rise under different conditions.

Mathematical Modelling of Tidal Circulation and Far-field Pollutant Transport

All of the previous studies apply in the near field, a region which is close to and dynamically affected by the introduction of the discharge. For understanding pollutant transport on a scale much larger than the water depth, numerical modelling of the long wave propagation and the advective transport in coastal areas using both the finite element and the finite difference method have been carried out. Emphasis was placed on studying the stability, accuracy, and efficiency of time-stepping numerical schemes, as well as on model verification. Figure 8a shows an example of computer maximum flood currents in Tolo Harbour (Lee, Li & Choi, 1985, Li, Cheung and Lee, 1986). A knowledge of the intra-tidal time variation of water levels and currents can aid greatly towards understanding the observed water quality in coastal waters. In addition, a capability of predicting astronomical tides based on a long or short series of tidal records at a given site has been developed since 1984. Given a year of continuous hourly tidal observations, a time history of tide levels can be generated to within 0.1m accuracy. Such a capability is essential for understanding the performance of tidal circulation models. Figure 8b shows an example prediction of tide levels at North Point; a comprehensive discussion of the analysis and prediction of tides has been reported (Lee, 1986).

There has been an effort to develop water quality transport models of varying degrees of complexity - ranging from relatively simple tidally-averaged models which may be more compatible with the available hydrographic and water quality data to 'real time' models which can handle transient problems better. Based on a prototype study, a time-dependent slack-tide oxygen balance model has been developed to interpret a set of dry season water quality data in a polluted tidal river (Lee & Choi, 1986). The model has been gainfully used in assessing the assimilative capacity (allowable pollution loading given a minimum acceptable dissolved oxygen level) in the tidal river. Supported by the Croucher Foundation, an ongoing research project on mathematical modelling of marine water quality is in progress under the supervision of Professor Y.K. Cheung of the same department.

Longitudinal Dispersion in Streams

Longitudinal dispersion refers to the combined effects of molecular diffusion, turbulent diffusion and cross sectional velocity variation on the spreading of a pollutant introduced into a stream. It plays an important role in the response of a stream to the discharge of pollutants. With an ever-increasing number of industrial wastes coupled with the lack of proper disposal facilities, pollutant releases to local streams are on the increase. If the downstream concentrations resulting from a routine/accidental release of a pollutant are to be predicted, a clear understanding of the mechanics of dispersion is essential. Predictions are required for taking appropriate measures during emergencies (eg an accidental spill of a toxic substance), and for setting limits for releases of common wastes.

Dispersion prediction involves three problems; firstly, the physical/chemical/biological processes that would take place when a certain pollutant is discharged into a waterbody must be identified and quantified. They must then be simplied to make practical sense. A computer-oriented solution free from numerical instabilities must then be developed to solve the resulting equations. The Civil Engineering Department of the University of Hong Kong has been actively involved in studying the various facets of these problems since the late 1970s. A brief qualitative description of the work done is given below:

The dispersion coefficient

When expressed in a mathematical form almost all pollutant transport problems contain a term involving the dispersion coefficient (or an equivalent parameter). It is dependent upon the channel geometry and the flow parameters. Following the pioneering work of Taylor (1953, 1954), a great deal of research effort has gone into quantifying the dependence of the dispersion coefficient on hydraulic parameters (Elder, 1959; Fischer, 1967; among others). Their work, mostly carried out under laboratory conditions, did not always yield satisfactory results when applied to natural channels.

One common limitation associated with most descriptions of the dispersion coefficient in a one-dimensional framework is that they are applicable only after an initial period - often known as the convective period - has elapsed. The advective diffusion equation which describes the longitudinal dispersion process in terms of bulk flow parameters is not applicable until after cross-sectional mixing has significantly reduced cross-sectional concentration gradients. One way of overcoming this limitation is to consider the dispersion coefficient to be time dependent in such a way that the steady state value is attained asymptotically after the passage of the initial period.

Following this idea, a relatively simple model in which the dispersion process is considered as consisting of three stages was proposed (Jayawardena and Lui, 1983). After extensive laboratory experiments, using smooth and rough channel beds to achieve different mixing rates, the parameters of the model structure have been determined. The mathematical basis as well as the empirical inputs used in this formulation are given in the references cited.

Field studies

Field studies were carried out in a few selected Hong Kong streams during 1979-80 with the objective of verifying the proposed dispersion model. Tracer studies were carried out using sodium chloride in streams where the water quality was good, and Sulphorhodamine B in streams where the background pollution level was very hgih. Estimated dispersion coefficients using the proposed 3-stage model were found to be in satisfactory agreement with measured values (Lui and Jayawardena, 1983). The peak concentration of a pollutant has only a weak (square root) dependence on the dispersion coefficient.

These conclusions are based on limited field data. More field data of an intensive nature are badly needed to reinforce the outcome of these studies. It is also feasible to imagine a situation where the controlling parameters of the longitudinal dispersion process could be read from tables compiled from field surveys just like the friction factor in the Manning's equation.

Numerical modelling

Numerical modelling is an essential part of prediction. For longitudinal dispersion prediction, a finite element - finite difference based numerical model which incorporates the time dependent dispersion coefficient has been developed. Guidelines for discretisation of the solution domain to prevent numerical instabilities have also been established (Jayawardena and Lui, 1983). An example of the application of this numerical model for the Lam Tsuen River is shown in Figure 9. The data for this example were taken from the above-mentioned tracer studies.

Dispersion through Porous Media

Relatively less attention has been given to pollution of sub-surface water perhaps because it cannot be seen. This is an important area of concern in regions where ground water is the source of public water supply. In Hong Kong groundwater pollution does not appear to be a serious threat at the present time, but the problem has to be addressed sooner or later. The response to sub-surface water contamination is very slow, giving a long lag time between cause and effect.

Infiltration of rain water through contaminated soils is one cause of sub-surface water pollution. This occurs to some extent in controlled tips. It can be a serious problem if the solid wastes in controlled tips contain toxic substances. The solutes travel through the unsaturated soils and reach the water table. Mathematically, it is a coupled problem which involves water movement in unsaturated soils. A solution to the latter problem must first be obtained and used in the solute transport problem.

Solution of the problem of water movement in unsaturated soils requires knowledge of soil hydraulic properties which can only come from actual measurements. It is labour intensive and time consuming. In the first instance, studies were carried out using reconstituted soils subjected to simulated rainfall under controlled conditions. Moisture movement has been monitored and compared with results obtained from a numerical model. Results have satisfactory and encouraging (Jayawardena, 1985; Jayawardena and Kalurarchchi, 1986). Following the establishment of the Kadoorie Agricultural Research Centre of the University of Hong Kong a field hydrological/environmental monitoring network has been set up and it is hoped that in the near future some of the data collection could be automated.

The concentration of solutes moving through unsaturated soils follows a profile which is similar to the soil moisture profile vs depth. Figure 10 is based on a dispersion experiment carried out in the labortory using sodium chloride as a tracer and shows the similarity between the volumetric moisture content and the solute concentration when plotted against a function of depth and time. Work related to the estimation of dispersion parameters and prediction of soluted concentrations is currently pursued.

Stochastic Modelling

For planning and design purposes, it is often necessary to understand the long term behaviour of a system. The environmental variable is then considered as consisting of a deterministic component with an outcome which can be determined with some degree of certainty and a stochastic component with an outcome attributed to chance and which can therefore only be described in probabilistic terms. The historical data, usually in the form of a time series, are decomposed into trend, cyclic, dependent and independent components and then synthesised by working in the reverse sequence, starting from a new generated sample of the particular probability distribution function which fits into the independent component.

Research in this area of study commmenced as a result of a UNESCO-sponsored project in which several teaching modules for strengthening the postgraduate curriculum in Environmental Engineering were developed. These were backed by several software packages which included stochastic modelling.

Successful generation of synthetic sequences of several hydrological variables have been achieved (Jayawardena, 1986).

Modelling of Denitrification in the Activated Sludge Process

Nitrogen in municipal wastewater is recognized as an important source of nitrogen in natural waters; raw municipal wastewater generally contains 15-50 mg/l of nitrogen. It is well known that nitrogen in its various forms in natural waters can have several adverse effects:

i) ammonia nitrogen exerts an oxygen demand in the receiving water, is toxic to fish, and requires large amounts of chlorine for disinfection during the treatment of water to potable standards;

ii) inorganic nitrogen can cause eutrophication of lakes and landlocked water bodies (such as Tolo Harbour in Hong Kong), resulting in the uncontrolled growth of algae and other aquatic plants;

iii) nitrate nitrogen in excess of 10 mg/l is unsuitable for consumption by babies because of the risk of methae-moglobinaemia.

Adverse effects caused by nitrogen in the ammonia form can readily be elminated by conversion to the nitrate form, which is the process of nitrification commonly used in wastewater treatment plants. However, when the effects are due to nitrogen in the nitrate form, removal of nitrogen is necessary. The available methods (Reeves, 1972, Bailey *et al*, 1975, Christensen *et al*, 1977) range from physico-chemical methods such as ammonia stripping and ion-exchange to biological methods such as biological nitrification-denitrification. At present, the most widely accepted method is biological nitrification-denitrification. Of the many biological nitrification- denitrification systems proposed, it is considered that a suitable system for use in Hong Kong is the integrated activated sludge system with anoxic zone(s), investigated by the Water Research Centre in the United Kingdom (Bailey *et al*, 1975, Cooper *et al*, 1977); this system requires a smaller plant than a separate system, can be operated without an additional carbon source and achieves energy saving by utilization of nitrate oxygen for BOD removal. This system is used in the Shatin Sewage Treatment Plant for removing a significant proportion of the nitrogen in the plant influent. However, no attempt has been made to develop a quantitative model to describe the performance of this integrated system. Therefore, as a start, research was initiated to develop and verify a suitable model for an integrated system with a single anoxic zone. The following is a brief account of the research undertaken.

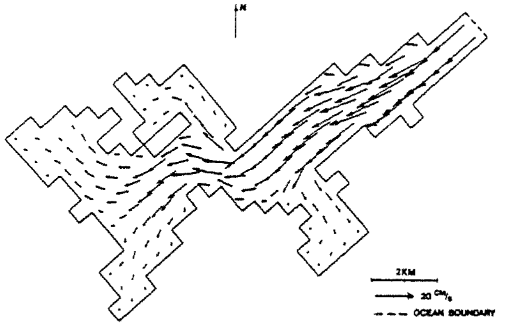


Fig.8 a) Example of computed flood currents in Tolo Harbour.

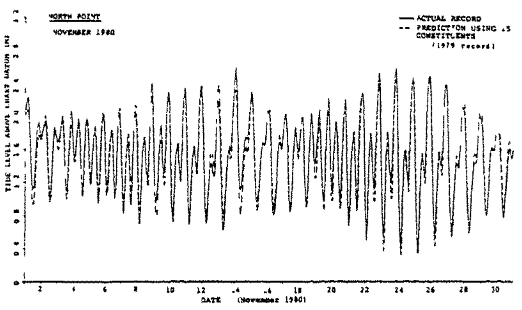


Fig.8 b) Example of tide prediction at North Point.

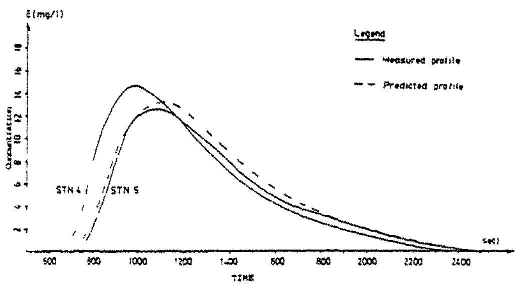


Fig.9 Comparison of predicted and measured tracer concentration using field data.

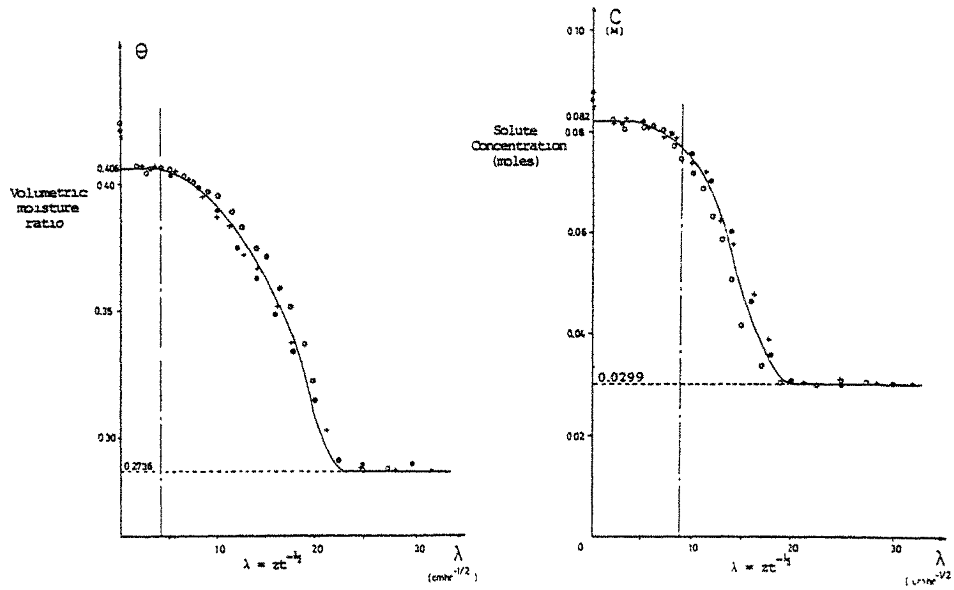


Fig.10 Predicted and observed volumetric moisture content θ and the solute concentration (moles) versus depth and time, $\lambda = zt^{-1/2}$. The three different symbols correspond to 1,2 and 4 hours since infiltration commenced.

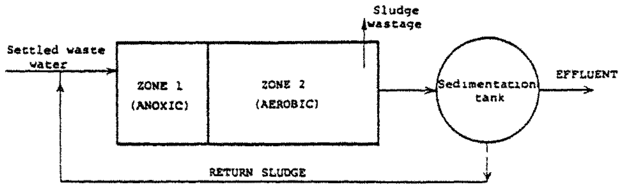
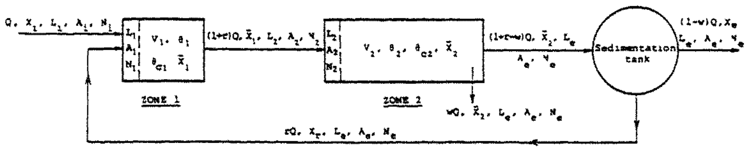


Fig.11 a) Operational configuration of an 'integrated' system for biological nitrification-denitrification.



Definition of Symbols:

Q	= influent flowrate	r = recycle ratio	V, V_1, V_2	= volume of aeration tank, zones 1 & 2 respectively.
w	= ratio of sludge wastage flowrate to influent flowrate		θ, θ_1, θ_2	= detention time in aeration tank, zones 1 & 2 respectively.
L,A,N	= soluble BOD_5, kjeldahl nitrogen and nitrate nitrogen at depicted locations (subscripts i, 1, 2, e denote influent, inlet to zone 1 & 2, and effluent respectively)		θ_{c1} θ_{c2}	= mean cell residence time in zones 1 & 2 respectively.
			X_i, $\bar{X}_1$, $\bar{X}_2$ X_r, X_e	= volatile suspended solids (VSS) concentrations in the influent, zones 1 & 2, return sludge and effluent respectively.

Fig 11 b) Schematic diagram for formulation of mass balances and kinetic equations in zone 1, zone 2, and the sedimentation tank.

Table I
Summary of equations in model of biological nitrification-denitrification.

ZONE 1

$$\theta_{c1} = \frac{\theta_1 \bar{X}_1}{(1+r)\bar{X}_1 - (X_i + rX_r)} \quad (3)$$

$$\bar{X}_1 = \frac{Y_N \theta_{c1}(1+r)(N_1 - N_2)}{\theta_1(1+\theta_{c1}k_{dN})} \quad (4)$$

$$N_2 = \frac{K_N(1 + k_{dN}\theta_{c1})}{\hat{\mu}_N \theta_{c1} - (1+k_{dN}\theta_{c1})} \quad (5a)$$

$$\frac{N_1 - N_2}{\ln(N_1/N_2)} = \frac{K_N(1+k_{dN}\theta_{c1})}{\hat{\mu}_N \theta_{c1} - (1+k_{dN}\theta_{c1})} \quad (5b)$$

$$L_2 = L_1 - \alpha(N_2 - N_1) \quad (6)$$

$$A_2 = A_1 - \beta\left[\frac{(1+r)\bar{X}_1 - rX_r}{(1+r)}\right] \quad (7)$$

$$L_1 = \frac{L_i + rL_e}{1+r} \quad (8)$$

$$A_1 = \frac{A_i + rA_e}{1+r} \quad (9)$$

$$N_1 = \frac{N_i + rN_e}{1+r} \quad (10)$$

ZONE 2

$$\theta_{c2} = \frac{\theta_2 \bar{X}_2}{(1+r)(\bar{X}_2 - \bar{X}_1)} \quad (11)$$

$$\bar{X}_2 = \frac{Y_L \theta_{c2}(1+r)(L_2 - L_e)}{\theta_2(1 + \theta_{c2}k_{dL})} \quad (12)$$

$$L_e = \frac{K_L(1 + k_{dL}\theta_{c2})}{\hat{\mu}_L \theta_{c2} - (1+k_{dL}\theta_{c2})} \quad (13a)$$

$$\frac{L_2 - L_e}{\ln(L_2/L_e)} = \frac{K_L(1 + k_{dL}\theta_{c2})}{\hat{\mu}_L \theta_{c2} - (1 + k_{dL}\theta_{c2})} \quad (13b)$$

$$A_e = \frac{K_A}{\hat{\mu}_A \theta_{c2} - 1} \quad (14a)$$

$$\frac{A_2 - A_e}{\ln(A_2/A_e)} = \frac{K_A}{\hat{\mu}_A \theta_{c2} - 1} \quad (14b)$$

$$N_e = N_2 + (A_2 - A_e) - \beta(\bar{X}_2 - \bar{X}_1) \quad (15)$$

$$X_r = \frac{(1 + r - w)\bar{X}_2}{r} \quad (16)$$

Notes:
i) Suffices N, L and A refer to the processes of nitrate nitrogen, BOD^5 and ammonia nitrogen removal respectively.
ii) Eqn 5a), 13a) & 14a) are applicable to complete-mix reactors, while Eqn 5b), 13b) & 14b) are applicable to plug-flow reactors.
iii) α and β are constants.

Table II
Experimental parameters and nitrogen removal efficiencies.

Run No.	1	2	3	4	5	6
θ (hr)	8	8	8	8	6	4
θ_1 (hr)	2.67	2.67	2.67	2.67	2	1.33
θ_2 (hr)	5.33	5.33	5.33	5.33	4	2.67
w	0.048	0.033	0.022	0.017	0.025	0.017
r	1	1	1	1	0.75	0.5
Observed Nitrogen Removal Efficiency (%)	19.7	59.5	59.6	57.1	48.1	41.6
Predicted Nitrogen Removal Efficiency (%)	18.8	58.2	56.2	57.5	51.7	46.0

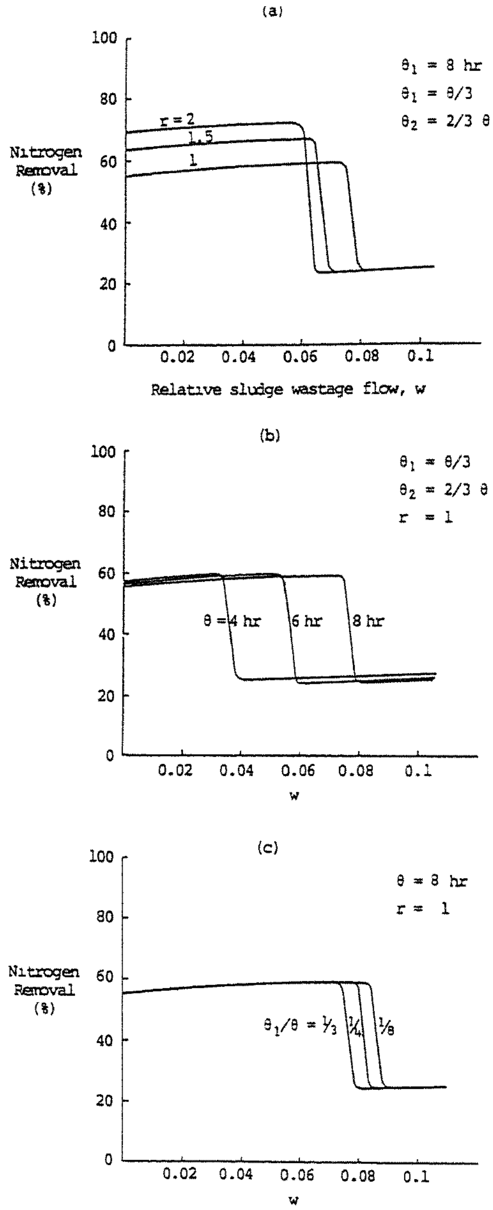


Fig.12 Predicted nitrogen removal efficiencies as a function of sludge wastage flow rate (relative to influent flow) for different operating parameters. Kjeldahl nitrogen and BOD in influent = 46 mg/l and 170 mg/l respectively. Temperature = 20°C, pH = 7 dissolved oxygen concentration in aerobic zone = 2 mg/l.

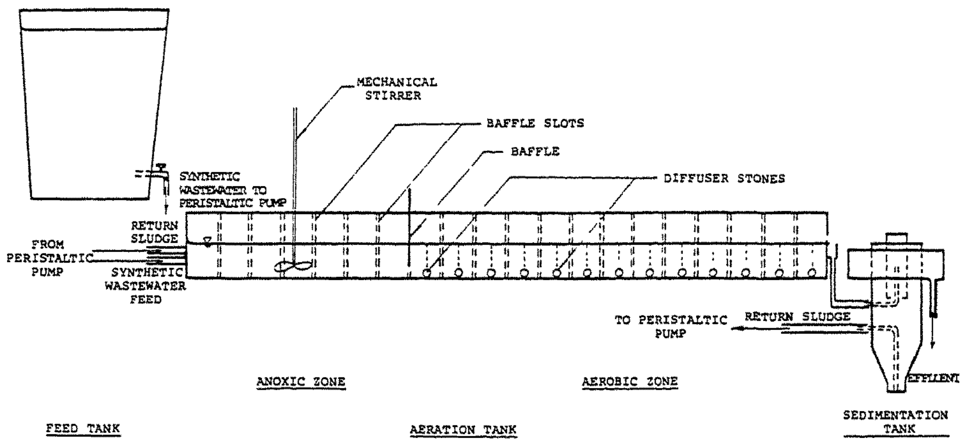


Fig.13 Schematic diagram of laboratory-scale model.

Formulation of kinetic model

The operational configuration ofn the 'integrated' system with a single anoxic zone is shown in Figure 11. The kinetic model for this system can be developed from two well-accepted kinetic equations (Lawrence & McCarty, 1970):

Mass Balance: $$\frac{1}{\theta_c} = YU - k_d \qquad (1)$$

Monod eqn: $$\mu = \mu\left(\frac{S}{K_s + S}\right) \qquad (2)$$

where:

μ = specific growth rate (d^{-1}),
μ = maximum specific growth rate (d^{-1}),
U = specific substrate utilization rate (d^{-1}),
Y = growth yield coefficient,
k_d = endogenous decay coefficient (d^{-1}),
S = substrate (BOD, ammonia or nitrate nitrogen) concentration in mg/l
θ_c = mean cell residence time (d).

The complete set of equations forming the model is given in Table I.

In zone 1, biological denitrification takes place. By considering this zone as a separate system (Figure 11b) and using eqn. 1-2, eqn. 3-5 can be obtained. As biological denitification proceeds, some carbonaceous matter in the wastewater will be used up and the resulting reduction in BOD concentration is deemed to be proportional to the reduction in nitrate nitrogen concentration, which gives rise to eqn. 6. As anoxic conditions are maintained in the zone, no nitrification occurs. However, a portion of the kjeldahl nitrogen is assimilated into cell tissue and the change in kjeldahl nitrogen is given by eqn. 7. Eqn. 8- 10 are obtained by considering mass balances of BOD_5, kjeldahl nitrogen and nitrate nitrogen concentration in the influent, the return sludge and the resulting mixture.

In zone 2, biological carbonaceous oxidation and nitrification take place simulatenously. Again by considering the zone as a separate system (Figure 11b), eqn. 11-14 can be similarly derived. In the derivation of these quations, the decay of the nitrifiers is ignored and organic nitrogen is considered to be completely converted to ammonia nitrogen. A portion of the ammonia nitrogen removed is assimilated into cell tissue while the rest is oxidized to nitrate; this is described by the nitrogen balance equation, eqn. 15.

It can be seen from eqn. 3-15 that there are 13 equations and 14 unknowns: O_{c1}, O_{c2}, X_1, X_2, X_r, N_1, N_2, N_e, L_1, L_2, A_1, A_2, and A_e. The reamining equation (eqn. 16) is furnished by considering a solids balance across the sedimentation tank (Figure 11b) and assuming that

i) X_e is negligible compared to X_2 and X_r, and

ii) negligible biological activities occur in the sedimentation tank.

Eqn. 3-16 provide a complete set of equations which allow the determination of the performance of the entire system by an iterative procedure once the operational parameters w, r θ_1, and θ_2 are specified. Figure 12 shows typical predicted nitrogen removal efficiency of the system as a function of these operational parameters.

Experimental investigation and results

A laboratory-scale model was used to verify experimentally the developed kinetic equations. In order to control the organic and ammonia nitrogen load to the laboratory model, a soluble synthetic wastewater with a BOD_5 of 170 mg/l and a kueldahl nitrogen concentration of 46 mg/l to simulate local settled municipal wastewater was used throughout the experiments.

Figure 13 shows the continuously-fed model used in the experiments. The model consisted of a feed tank, an aeration tank and a sedimentation tank. The aeration tank was a rectangular channel (0.1 x 0.2 x 2 m) made of plexiglass and divided into an anoxic zone and an aerobic zone by a transverse baffle. Vertical slots were provided at intervals along the channel for insertion of baffles to very, if desired, the volumes of the anoxic/aerobic zones. A peristaltic pump with two tubes was used to feed in synthetic wastewater and to retun settled sludge in the sedimentation tank to the inlet of the aeration tank.

The kinetic equations developed indicate that the performance of the system depends on four operational parameters: w, θ_1, θ_2 and r. A series of experiments were therefore designed and carried out with different values of these parameters (Table 2). Separate experiments were carried out to determine the kinetic coefficients for carbonaceous oxidation, nitrification and denitrification for the synthetic wastewater. Laboratory-scale activated sludge models similar to those described in the literature (Hatfield *et al*, 1954, Balakrishnan ,1968) were used in these experiments.

Table 2 shows the observed and predicted nitrogen removal efficiencies for the six runs performed. It can be seen that there is good agreement between the two sets of figures. Also, the observed BOD removal efficiency in the experiments ranged from 94 to 99%, while the predicted value was about 99%. Therefore, in general, it can be said that the validity of the kinetic equation is confirmed.

Concluding Remarks

An overview of civil engineering research related to the environment has been given. Some of the research has indirectly benefitted both out undergraduate and post-graduate teaching and will be injected into the planned curriculum for the forthcoming HKU inter-disciplinary M.Sc. (Environmental Management) programme.

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