PUBLIC HEALTH ENGINEERING—DESIGN IN METRIC

WASTEWATER TREATMENT

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Preface

THE period of change to the use of the metric system in the U.K. is a convenient time to review developments and trends in the treatment of sewage and industrial wastes, and to re-state existing practices in metric units.

Public Health Engineering—Design in Metric: Sewerage was published in 1970. While this second *Design in Metric* book has been written as a companion volume, it is intended to be complete in itself as far as possible, and to include all engineering aspects of the design of treatment works for sewage and industrial wastes. A few of the tables and other details from the earlier book have therefore been reproduced for easy reference.

Of about 5 000 municipal sewage treatment works in England and Wales, over 80% serve populations of under 10 000. This book has been written mainly with smaller and medium-sized treatment works in mind, although in some respects it will be equally applicable to larger works. The subject has been divided into chapters according to the type of treatment process, although the chapters, of necessity, overlap to some extent. Considerable reference has been made to technical papers and articles published in recent years and a full bibliography is included.

Within the metric system there have been many different but related systems of units; these have included the centimetre-gramme-second (cgs) and the metre-kilogramme-second (MKS). The S.I. (Système International D'Unités) has been adopted in the United Kingdom as a rational system of units to be used throughout the country, and the *Report of the Working Party on Metric Units with Reference to Water, Sewage and Related Subjects* was drawn up on that basis. The metric system (S.I.) has been used throughout the book *without* reference to the equivalent imperial units. A conversion table is included at Appendix F for comparison when required.

As with *Design in Metric: Sewerage,* I have avoided detailed theoretical design and abstruse calculations as far as possible, and, as they change so quickly, very little reference has been made to costs of construction. While it is intended mainly for engineers engaged on the design and construction of treatment works, I hope that the book will be equally useful to students.

I am indebted to the many authors and manufacturers who have given me permission to quote from their publications, and to those who have authorized the reproduction of illustrations and other details. My thanks are particularly due to Mr. J. W. Tubby, M.Inst.W.P.C., and others for reading through the manuscript, and to my wife and family for typing, checking and proof-reading.

R.E.B.

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1 Introduction

THE disposal of waste waters became a necessity as soon as humans began to live in organized communities. Various ancient civilizations around the world used pipes or culverts as sewers, but the *treatment* of the sewage no doubt followed at a much later period. The development of industries and the installation of water closets early in the nineteenth century led to the development of drainage systems for the removal of offensive wastes both from the industries and from the houses.

The drains and sewers constructed during that period merely transferred the pollution from the houses and factories to the rivers. The outcome was a deterioration in the standards of many river waters so that fish were killed and the water became useless for either domestic consumption or for industrial use. This effect was very marked in some rivers near towns and cities; the River Thames at London became so polluted that by 1855 it was impossible to use the rooms on that side of the Houses of Parliament, and it has been reported that curtains saturated with chlorine of lime were used to mask the foul smells of the river.

Outbreaks of disease due to the use of polluted rivers as sources of drinking water led to the appointment of a number of 'Commissions' and to the passing of various Acts of Parliament. The result was the establishment of 'sewage farms' at many town and cities to provide some form of treatment to the sewage before its discharge to the river. The reports of the Royal Commission on Sewage Disposal which sat from 1898 to 1915 have formed the basis of much of the present-day practice in sewage treatment in the U.K.

The capital expenditure on the construction of sewerage and sewage disposal schemes in England in 1969 was about £110 million. The revenue expenditure for the same year has been estimated at £106 million. These figures exclude any direct expenditure by industry on effluent treatment. The revenue expenditure (excluding any capital repayment element) is equivalent *on average* to about £1·00 per 15 m^3 of sewage treated.

With the increase in the use of surface waters as sources of potable water supply, there is now a greater emphasis on the control of river water quality and on the reduction of pollution generally. A Government White Paper (Cmnd 4373) on 'The Protection of the Environment: The Fight against Pollution' was issued in 1970. In the same year, a standing Royal Commission was set up 'to advise on matters, both national and international, concerning the pollution of the environment; on the adequacy of research in this field; and the future possibilities of danger to the environment'.

The Technical Committee on Storm Overflows and the Disposal of Storm Sewage published its Final Report in 1970, and the Lena Jeger Working Party on Sewage Disposal issued its report 'Taken for Granted'; this latter report has been referred to later as the Jeger Report. More emphasis is now being given to the need for the control of pollution of the nation's rivers and streams, and the need for adequate treatment facilities for sewage and industrial wastes.

DEFINITIONS AND ABBREVIATIONS

A first essential is to establish the meanings of a few of the more commonly used expressions. More detailed lists of definitions and abbreviations are included in Appendix C.

The term 'sewage' is generally used to refer to water-borne human wastes. It will almost certainly include domestic wastes and it may include industrial effluents, subsoil or surface water. Industrial effluents (or trade wastes) in the present context are those wastes from industrial premises (including farms) which are discharged either to a sewer or to a watercourse. 'Sewerage' refers to the system of sewer pipes, manholes and other ancillary works constructed to convey the sewage from its point of origin to a point of disposal.

A sewerage system is referred to as a 'separate' system when the sewers have been designed to carry *only* foul sewage, i.e. only waters contaminated with domestic or industrial wastes, or *only* surface water. 'Combined' sewers are those designed to carry both foul sewage and surface water. 'Partially separate' sewers are to some extent a compromise, and are designed to carry the foul sewage plus *a part* of the surface water; this will often be the run-off from back roofs and yard gullies.

The flow of sewage during a period of dry weather is referred to as the 'dry weather flow' (d.w.f.). This is frequently defined more specifically as the daily rate of flow of sewage, together with infiltration, if any, in a sewer in dry weather; this may be measured after a period of seven consecutive days of dry weather during which the rainfall has not exceeded 0·25 mm.

Concentrations of solids or other impurities in sewage were originally referred to in parts per 100 000. This was subsequently amended, and the quantities were expressed in parts per million (p.p.m.). It is now more general to use the equivalent term of milligrammes per litre (mg/l).

An expression used frequently in the U.K. with reference to effluent standards is the Royal Commission Standard. This refers to the recommendations in the 8th Report of the Royal Commission on Sewage Disposal which was published in 1912. In modern terminology, this 'standard' refers to a liquid which contains not more than 30 mg/l of suspended solids, and not more than 20 mg/l of biochemical oxygen demand (BOD) (see Chapter 4). This is often abbreviated as the 30:20 standard.

THE PROBLEM

Domestic sewage contains the waste water from baths, kitchens and toilets. In addition, sewage usually contains some rainwater either in the form of infiltration through faulty pipes or joints, or as surface water run-off from roads, drives, roofs, etc. The characteristics of any industrial waste waters will, of course, vary from one industry to another. The resulting mixture in the sewers will contain organic and inorganic matter, including soaps and grease; this will be partly in suspension, partly colloidal and partly in solution. The normal solids content of sewage is extremely low; this is often less than 0·1%, i.e. the sewage will contain 99·9% or more of water. The quantity of sewage per head (in terms of d.w.f.) varies from about 100 to 300 litres per day; the lower figures generally apply to rural districts, while the upper figures may apply to new development. Higher figures of up to 450 litres per day or higher are met in parts of the U.S.A. and Canada, but the strengths of those sewages are generally lower than those of the U.K.

The original aim of sewage *disposal* was the removal of the waterborne wastes from domestic and industrial communities without causing any danger to health. Disposal did not necessarily include treatment. The principal aim of sewage *treatment* is to remove as much of the solids content as is practicable and economical, and then to oxidise (and subsequently remove) the colloidal and dissolved solids. The effluent when discharged should not pollute the stream, be a danger to public health, or cause a local nuisance. The method of treatment chosen for any particular installation will depend on the quality of effluent required and on the area and type of land available. The method chosen should preferably be the most economical (in annual costs) and should not cause a nuisance to adjacent properties by noise, smells or insects.

Whenever it is possible, the design engineer should consult with, and obtain advice from, both the works manager and the chemist (plus, if necessary, a microbiologist and biochemist), before making any decision on methods of treatment or on the capacity of units for the works. 'There can be no completely stereotyped system of sewage treatment, and individual works, although conforming to the same broad principles, must be designed and operated in accordance with the characteristics of the particular sewage to be dealt with' [214].

Water usage in the U.K. is increasing by about 3% per year, and this will continue to increase as more houses are provided with modern sanitation, and as the use of water in washing machines and dishwashing machines and for car-washing increases. It has been estimated that by the year 2000, the total volume of domestic and industrial effluents may have doubled, so that even to maintain the present standards in the country's rivers and streams, the hydraulic capacity of the sewage treatment facilities of the country would need to be more than doubled. The Jeger Report stresses the need for continual liaison between planning and sewage disposal authorities so that sewage treatment facilities can be kept in step with the demand, but it points out that the cost of sewage treatment works built in advance of development, especially for increases in population, could be a heavy burden on existing ratepayers.

That report also stresses the complex nature of sewage, and the need for a proper understanding of the treatment processes. The higher and more consistent standards of treatment required cannot be fulfilled without the necessary technical staff; this applies as much to the civil engineering design staffs as to management and operatives.

The modern tendency is towards regionalization of sewers and treatment works. While some of the very small works are undoubtedly inefficient and uneconomical, any proposal for a regional scheme must be carefully costed (including the cost of the trunk sewers), before any decision is reached. Many engineers feel that, while regional schemes may have their place in the more urban areas, there are areas which are not yet fully developed where it would be extremely difficult to forecast future population figures, and therefore to design an economical system of trunk sewers. A regional scheme under those conditions could result in the construction of unnecessarily large trunk sewers which would never run at their design flow, or alternatively, to the construction of small sewers and their early duplication due to overloading within a few years.

WATERBORNE DISEASES

The dangers of inadequate disposal of sewage and other waste liquids arise mainly from the pollution of water supplies, and to some extent from the pollution of the land. The pollution of river waters not only results in harm to fish and other aquatic life due to depletion of oxygen in the water, it can also lead to gastro-intestinal complaints when the water is subsequently used for drinking. More important, however, is the possible contamination of the water by pathogenic organisms such as bacteria and protozoa, the eggs of parasitic worms, and various viruses. The normal methods of sewage treatment do not remove all of these organisms. Crude sewage will normally contain millions of bacteria per millilitre, but usually only a small number of these are pathogenic.

Bacterial diseases in temperate climates include typhoid, the paratyphoids and bacillary dysentery. In tropical and sub-tropical countries there are the additional possibilities of both amoebic dysentery and of cholera; *vibrio cholerae* are contained in the faeces of infected persons and became disseminated by means of drinking water as well as by person-to-person contact. The extensive outbreaks of cholera which occurred in London around the middle of the nineteenth century led to Dr. John Snow's deduction of the link between this disease and drinking water supplies.

While bacteriologists are now able to isolate enteric organisms within a small community and can often locate the actual house of a 'carrier', typhoid bacilli have a long period of survival in sewage, even in sludge which has been subjected to heated digestion. One of the most satisfactory sewage treatment methods for the removal of bacteria and of eggs of intestinal parasites is slow sand filtration; other tertiary treatment methods such as lagoons and grass plots have also proved effective.

Parasitic worms and flukes spread by poor sanitation include those of hookworms, schistosomes, roundworms and threadworms. The eggs of these parasites can survive for many months outside the human body and are therefore easily transferred from one person to another if food is directly contaminated with human waste.

The more important virus diseases include poliomyelitis and infective hepatitis. Both of these viruses have been located in sewage and in sewage-contaminated waters. Preventative measures for infective hepatitis include good community sanitation and personal hygiene.

CHARACTERISTICS OF DOMESTIC SEWAGE

Normal domestic sewage, if fresh, is a greyish turbid liquid; if septic the colour will be much darker and the liquid will have a foul smell. The inclusion of any industrial effluents can alter both the colour and smell. An average domestic sewage in the U.K. has a suspended solids content of about 350 mg/l. Those solids are made up of organic matter (faeces, soap, paper, vegetable matter, etc.) together with inorganic matter such as grit. This type of sewage, when treated, yields about a litre of sludge per person daily (at 95% moisture content).

During putrefaction, and during aerobic oxidation, changes take place in the sewage due to bacterial action. The organic matter in the sewage (in the presence of oxygen) provides food for the bacteria which secrete enzymes, while protozoa feed on the bacteria themselves. The raw material is therefore continually changing throughout the treatment process.

Analyses of sewage are normally expressed under the following main headings; suspended and dissolved solids, biochemical oxygen demand (BOD), chlorine, ammonia, nitrites and nitrates, and acidity or alkalinity. These aspects are considered in more detail in Chapter 4. Physical analyses are made to assess the temperature, colour and smell. Occasionally the turbidity is measured in addition to the determination of the suspended and dissolved solids.

The results of a survey organized by the Institute of Water Pollution Control, along with data supplied by the Water Pollution Research Laboratory, indicate that an *average domestic crude sewage* in the U.K. has the following loadings:

BOD	51 to 60 g/head day
suspended solids	60 to 85 g/head day
permanganate value	11 to 15 g/head day
ammoniacal nitrogen	3 to 8 g/head day.

INDUSTRIAL WASTES

The strength of any sewage is very dependent on the amount of industrial waste which it contains. According to the Jeger Report, the proportion of industrial waste in sewage is about 50% *on average*; it is certain of these wastes which present the greatest problems in sewage treatment.

Recent legislation in the U.K. has given local authorities the right to charge for the reception of industrial wastes into their sewers and/or to require some form of pre-treatment before their acceptance. The charge is levied on the industrialist, and usually takes into account the cost of conveying and treating the liquid and of the disposal of any sludge. The method of charging is generally based *pro rata* on the cost of treating all sewage and industrial wastes received at the treatment works, taking into account certain aspects of both the quality and quantity of the particular industrial waste (see Chapter 15). Any more detailed method of charging would probably be costly to enforce and the additional expense would not be justified except for an industrial undertaking discharging large quantities of effluent. Various types of industrial effluents and methods of charging are considered in Chapters 15 and 16.

When a new industry is being developed it will be to the advantage of both the industrialist and the local authority if the manufacturing processes are planned to reduce the volume of waste water to a minimum; one waste should also be used to neutralize another whenever this is practicable. It may often be in the industrialist's interest to give some form of pre-treatment to the waste before this is discharged to the sewer; this could substantially reduce the charge made by the local authority, particularly if the BOD value of the waste is high compared with domestic sewage.

CONTROL OF RIVER POLLUTION

A national clean rivers programme would aim to make the rivers of a country suitable sources of water supply and also to make them suitable for recreation, as well as for agricultural and industrial usage. While an informal survey of the rivers in the U.K. in 1958 showed that *most* lengths were unpolluted, considerable lengths throughout the more densely-populated areas were then classed as 'grossly polluted'.

Pollution of a watercourse can be caused by a reduction in the dissolved oxygen in the water, by the addition of suspended and settleable solids, or by the addition of poisonous substances such as chromium and cyanide. If untreated or inadequately treated sewage or industrial wastes are discharged to a river, the suspended solids tend to settle to form banks of sludge, and the organic matter in the sewage takes up oxygen from the river water, thereby depleting its oxygen content (so necessary for fish and other life). Any poisonous substances present may, of course, directly affect fish or other aquatic life in the river.

If a stream is in a 'healthy' condition and the pollution is not excessive, any organic matter discharged to it will be broken down and the dissolved oxygen content of the water will slowly increase to its former value. The effluent from the treatment of domestic sewage is not normally in itself harmful to fish life, provided the level of dissolved oxygen in the river is not reduced below the asphyxiation point. Fish have in fact been maintained in undiluted domestic sewage effluent provided it contained sufficient dissolved oxygen. The physical condition of the stream will, however, have an effect on the self-purification process; important aspects are the depth and velocity, the turbulence of flow, the temperature of the river water, any deposits of mud, and the scarcity or abundance of plant life.

If the discharge of effluents to a river exceeds the amount which can be oxidized naturally by the river water, the effect will be cumulative. The oxygen in the river will be slowly used up and the frequent discharge of sewage or other wastes along the course of the river will impair the recuperative powers of the water. Some of the organic solids in the sewage or effluent will settle on the river bed, and gases will be given off from this material so that the river acquires a fetid odour; it becomes permanently polluted and a danger to the health of the community.

The Jeger Report referred to the many miles of rivers in the U.K. which have been 'regained as fisheries', and referred to the reduction in pollution over the last few years despite increases in the volume of effluents discharged. A Ministry Circular (No. 44 of 1970) has stressed the need to accelerate progress in improving water supplies, sewerage and sewage treatment, and the qualities of rivers.

Over the last few years there has been an increase in the use of rivers and canals for pleasure cruising. Many of the boats in use discharge their lavatory and kitchen wastes directly into the water, thereby increasing the pollution, particularly at marinas and other places where the boats congregate. Byelaws can be made under the Rivers (Prevention of Pollution) Act, 1951, to prohibit these discharges, but these would be difficult to enforce.

The emphasis over the last few years has been more on the re-use of river waters and less on possible nuisance and the effects on fish life. The emphasis is now more on the need for water conservation, with either its re-use by industry (after treatment at the factory itself), or its use to replenish surface waters and ground waters. Many of the rivers in the U.K. rely on the supply of treated effluents to maintain their flows in dry weather. The water supply for nearly 25% of the population of England and Wales is now derived from rivers which have received sewage effluents upstream of the water intakes. Where the water is abstracted from lakes or reservoirs fed by rivers, the possibility of eutrophication (the enrichment of the water by plant nutrients) is becoming an increasingly important consideration; this process is accelerated by the discharge of domestic and industrial wastes to the rivers and by the run-off and leaching from fertilized agricultural land.

The Technical Commission on Pollution of Surface Waters (of the International Water Supply Association) has recommended that where a river is to be used as a source of drinking water, the BOD of the river water at the point of intake should not exceed 4 mg/l, the dissolved oxygen content should not be less than 70% of saturation, and the ammoniacal nitrogen content should not exceed 0·5 mg/l. The Commission also recommended that the desirable limit for chlorides should be 200 mg/l, that phenols should not exceed 0·001 mg/l, and that there should be no oils or fats. In its 1961 Edition of *European Standards for Drinking Water*, the World Health Organisation pointed out that there was a danger of infantile methaemoglobinaemia if water was consumed which contained more than 50 mg/l of nitrates (as NO_3); in their 'International Standards', the W.H.O. proposed a *maximum allowable limit* of 45 mg/l.

TREATMENT AND DISPOSAL OF SLUDGE

In the past, the disposal of the sludge resulting from sewage treatment has tended to be considered less seriously at the design stage than the treatment of the sewage itself. It is now recognised that efficient and economical treatment of the sludge is an integral part of the whole treatment works, and that the design of this part of the works must be integrated with other aspects. Inefficient or insufficient treatment of the sludge can adversely affect the standard of the effluent from a works, and can also be the cause of complaints arising owing to smells. Higher standards of effluent control have resulted in larger quantities of sludge, while labour shortages and higher costs of land have emphasized the need for mechanization. Sludge treatment and disposal can, in fact, account for a large part of the cost of sewage treatment.

Each works must be considered separately in this respect. A decision must be reached as to whether the sludge should be disposed of in its liquid state as manure for agricultural ground (or by dumping at sea); in a semi-dry state (40 to 50% moisture) for agricultural purposes or as a filling material; as a dry product (10% moisture or less); or by composting with other refuse. Whichever method is adopted will affect the physical layout of the sewage treatment works and will affect the amount, if any, of conditioning of the sludge before treatment.

LEGISLATION

In the U.K., legal and administrative control over pollution is well established. During the last few years the law relating to sewerage and sewage disposal has been brought up-to-date by a number of new Acts. Acts affecting the disposal of sewage and industrial wastes include the Salmon and Freshwater Fisheries Act of 1923, the Rivers (Prevention of Pollution) Acts of 1951 and 1961, the Clean Rivers (Estuaries and Tidal Waters) Act, 1960, and the Public Health Act, 1961. Scottish Acts include the Rivers (Prevention of Pollution) (Scotland) Acts of 1951 and 1965.

The 1923 Act provided that 'no person shall cause or knowingly permit to flow, or put or knowingly permit to be put, into any waters containing fish, or into any tributaries thereof, any liquid or solid matter to such an extent as to cause the waters to be poisonous or injurious to fish or the spawning grounds, spawn or food of fish'.

The 1961 Public Health Act, along with the earlier 1936 Act, has brought up-to-date the legislation on the discharge of industrial (i.e. trade) wastes, and a local authority may now specify conditions attached to any consent to discharge trade waste to a sewer, and make a charge for its reception and disposal.

The Rivers (Prevention of Pollution) Acts have established a system of control over new discharges of trade and sewage effluents to streams and rivers, and have made these subject to the consent of the river authority. The conditions which attach to new discharges as regards quality, temperature, volume, etc., can also be applied to earlier discharges. Under these Acts, a 'stream' includes any river, stream, watercourse or ditch (except a blind ditch) irrespective of whether it may be dry for part of the year.

The Pipelines Act of 1962 does not apply to the construction of sewers and drains. Effluent and sludge pipelines are classed as sewers, and are therefore also not at present covered by this Act. The Jeger Report has however recommended that the Act should be amended so that the same provisions would apply to cross-country pipelines of this type as now apply to oil and gas pipelines.