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# Developmet of a Process Selection Model for Industrial Wastewater Treatment Using an Expert System

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ABSTRACT

*A process selection methodology was developed for an industrial wastewater treatment plant. The starting point of the procedure was the categorisation of the wastewater based on industry type, general pollution indicators, or contaminant removal processes giving a standardised compositional code which consisted of seven basic wastewater characteristics. A preliminary design assessment was undertaken by comparing the influent parameters with the desired effluent quality or consent conditions; where an influent parameter was not known, a minimum characterisation set of analysis data was used. A preliminary process selection was carried out in terms of maximum volumetric loading rates and depths for each process which gave the required footprint area for the reactor. In addition to the reactor, the overall land area requirement was determined by incorporating the potential ancillary equipment such as sedimentation and sludge processing tanks for each process. The process selection was further refined by the establishment of performance graphs for each process, based on the volumetric loading rates and the percentage removal of COD or BOD. Based on these graphs, each process can be quantified as to whether the COD or BOD consent is met in relation to the respective volumetric loading rate. If there was not a performance envelope available for the process, data was sought from a treatability study in the laboratory. The methodology has been incorporated into an expert system shell (XpertRule), which runs on a P.C., and provides a simple user interface. Certain provisions are made available in the program for new information to be added into the knowledge base. The automation of the methodology currently allows the user to make a selection based on biological treatment process alternatives.*

ABSTRAK

*Satu tata kaedah proses pilihan telah dikembangkan untuk loji rawatan air buangan industri. Tata cara permulaannya ialah dengan mengkategorikan air buangan tersebut berdasarkan jenis-jenis industri, penunjuk-penunjuk pencemaran umum, atau proses-proses penyingkiran bahan-bahan lumus dengan memberikan satu kod komposisi terpiawai yang mengandungi tujuh ciri-ciri teras air buangan. Satu penilaian reka bentuk preliminari telah dijalankan dengan membandingkan parameter-parameter influen dan kualiti effluen yang dikehendaki atau nilai piawaian. Sekiranya terdapat sebarang parameter influen yang tidak diketahui, maka analisis data-data yang merangkumi satu set pencirian yang minima digunakan. Proses pilihan*

*preliminari tersebut telah dijalankan berasaskan kepada kadar pembebanan isipadu dan kedalaman yang maksima bagi setiap proses yang seterusnya memberikan luas kawasan tapak yang dikehendaki oleh reaktor. Selain dari reaktor, keperluan keluasan tanah keseluruhan ditentukan dengan memasukkan peralatan-peralatan sokongan yang berpotensi seperti tangki-tangki pengenapan dan pemprosesan enap cemar bagi setiap proses. Proses pilihan tersebut diperhalusi dengan lebih jauh lagi oleh penghasilan graf-graf prestasi untuk setiap proses berdasarkan kepada kadar pembebanan isipadu dan peratusan penyingkiran Permintaan Oksigen Kimia (COD) atau Permintaan Oksigen Biokimia (BOD). Berdasarkan kepada graf-graf tersebut, setiap proses boleh dikuantifikasikan samada nilai-nilai piawaian untuk COD atau BOD dipatuhi sehubungan dengan kadar pembebanan isipadu masing-masing. Sekiranya tiada graf prestasi yang tersedia untuk sesuatu proses maka data-data diperolehi daripada satu ujian kebolehrawatan yang dijalankan di makmal. Tata kaedah tersebut telah diaplikasi menggunakan satu kelompang sistem pakar (XpertRule) yang boleh dijalankan oleh satu komputer peribadi dan menyediakan satu antara muka pengguna yang mudah. Beberapa kemudahan dibuat tersedia ada didalam pengaturcaraan agar matlumat-matlumat baru boleh ditambahkan kedalam pangkalan pengetahuan. Pada masa ini, pengautomatikan tata kaedah tersebut membolehkan para pengguna membuat suatu pilihan berdasarkan beberapa alternatif dalam proses rawatan biologi.*

## INTRODUCTION

Polluted waters are generated from a number of sources including domestic premises, service industries, manufacturing industries, urban run off, agriculture and animal husbandry. Water consumption on a per capita basis is high and in developed countries may be as much as 200 litres per head per day, much of which arises as a result of industrial activity.

With increasing demand for higher water quality in receiving waters, pressure is being exerted for increased treatment capacity and enhanced performance for municipal waters and industrial effluents. Increasing cost, both for raw wastewater treatment and for sewer systems, has focused attention upon wastewater minimisation as well as methods for on site treatment in small compact plants prior to discharge.

Treatment technology for dealing with domestic, and even mixed industrial / domestic waste waters is well established and there is a well founded sequence of operations aimed at removing pollutants from the aqueous stream cost effectively. These comprise of screens, grit separation, sedimentation, biological oxidation and tertiary treatments (optional).

For industrial waste water, the case is not clear cut since any waste stream can exhibit its own characteristics which are primarily a function of the industrial process from which it is derived. The choice of equipment and sequencing of unit operations are not well defined and each case must be dealt with on an individual basis. This is a highly skilled task calling upon a combination of experience and interpretation of analytical results. The process is further refined by resorting to treatability studies, mass balance considerations, kinetics, and economic factors. There is no single methodology which is universally applied

for selecting the satisfactory combination of operations, and the whole procedure appears intuitive and in some cases quite arbitrary.
The aims of this study are thus:

1. To develop a process selection methodology of a hierarchical nature.
2. To retain flexibility in the approach to data input.
3. To make the system available to a wide number of users by incorporating the knowledge in a computer program.
4. To minimise the requirement for analytical data input and to produce a standardised data input format which would be universally applicable to the process selection procedure for industrial wastewater treatment.
5. To make the system easily expandable so as to be able to carry out detailed design tasks either by reference to empirical data banks or by calculation.
6. To make the selected series of operation primarily effective at meeting the required consent condition and secondarily the most cost effective solution in doing so.
7. To develop a process selection methodology which should not be biased towards any single (or combination of) treatment option(s).
8. To make the methodology applicable to a wide range of wastewater types.

The concept of minimising capital and running costs in the treatment of wastewater without jeopardising its efficiency and performance has been previously addressed by a number of researchers. A key element in this is through the proper and justified selection of unit operations which has always been regarded as the domain of the consulting engineer. Early tools to aid in process selection were in the form of a lead-in diagram which could be used for both municipal and industrial waste water treatment (Young 1990). A second process selection diagram (Adams 1994) depicts alternative process routes for industrial effluent treatment. The diagram is complicated as it covers the wide range of processes available, and necessary, for the treatment of complex industrial waste waters. Belhateche 1995 used a decision flowchart to assist in selecting the appropriate treatment processes for industrial wastewater by comparing processes in terms of their specific applications, and their respective advantages and disadvantages in an attempt to provide guidance on when to apply what type of treatment to which waste streams.

It is not surprising that since the 1960's the powerful processing capabilities of computers have been applied to the problem of process selection. Evenson et al. (1969) carried out a preliminary selection of waste treatment systems by means of a dynamic programming technique aimed at identifying a "best waste treatment system" to remove a specified amount of BOD and to treat the solids generated from the fruits industry. Chia and Krishnan (1969) also applied a dynamic programming technique to optimise an industrial wastewater treatment plant design. The optimisation method attempted to identify the optimum combinations and efficiencies of various unit processes in a multi-stage treatment plant in order to meet the desired final effluent quality with minimum cost. Ellis and Tang (1991) developed and Tang and Ellis (1994) tested a selection procedure specifically for domestic/municipal wastewater treatment optimisation with respect to developing countries by incorporating specialised features such as social, cultural and environmental influences likely to be encountered in the third world nations. The analytical technique used was a hierarchical analysis process using matrix data which consisted of 20 key parameters.

The first definition of an expert system was given by Professor Edward Feigenbaum of Standford University who defined an expert system as "an intelligent program designed to solve problems that are difficult enough and require significant human expertise for their solution" (Feigenbaum 1982). Finn (1989) defined an expert system as "a specialised computer program which has the ability to manipulate uncertain and non-numerical information to provide advice to a user in a particular problem area". Giarratono and Riley (1989) defined an expert system as "a computer system which emulates the decision-making ability of a human expert". Another definition of an expert system was given by Jackson (1990) who defined it as a "computer program that represents and reasons with knowledge of some specialist subject with a view to solving problems".

Little research has been carried out in the process selection of wastewater treatment using expert systems based on a cost-related basis. Galil et al. (1991) proposed an expert support system (ESS) to examine the process sequences in domestic/municipal wastewater treatment and sludge disposal. Spinos and Marinos (1992) developed an integrated computerised procedure not only for the selection and design of domestic/municipal wastewater or sludge treatment process but also to produce all the documents involved in the process design phase. Kao et al. (1993) developed a prototype computer-based design environment to facilitate domestic/municipal wastewater treatment plant design tasks using several mathematical techniques, interactive graphic displays and user-friendly interfaces. Okubo et al. (1994) developed a PC-based decision support system for selecting the most appropriate small scale domestic/ municipal wastewater treatment plant process for specific conditions namely: population and budget availability for construction, operation and maintenance.

In summary, it is fair to say that little work has been presented on the application of expert systems for process selection in the water industry. Relevance to this work is that an expert system methodology was applied in order to achieve the final objective, which in all of the cases, as different from those of this research. The approach used in those works exclusively relied on cost as the most important criterion for the process selection, whereas the current work emphasises more on the requirement to meet a final effluent quality, with cost considered as secondary to achieving a consent. For that reason, it was extremely difficult for the current study to build upon the previous work, due to the different approach adopted in the methodology. As such, it is appropriate that the methodology adopted in this research has been developed from first principles within the limitations of a commercial expert system shell.

## DESCRIPTION OF EXPERT SYSTEM SHELL

XpertRule (Al-Attar 1993) is a tool for knowledge based system development. It has a different knowledge representation and inference mechanism when compared to other rule based programming tools. The knowledgere presentation and inference mechanism of XpertRule are designed in such a way that knowledge structuring and acquisition tasks can be simplified, and bridges built to both conventional programming languages and conventional rule based systems.

XpertRule was chosen on the basis of its ability to carry out decision making tasks, and a list of appealing special features which which will be discussed below.

## BASIC KNOWLEDGE REPRESENTATION

The unit of knowledge within XpertRule is a decision making task represented by a decision tree which represents several nested production rules. The decision making task usually employs two criteria: an outcome (decision or conclusion) and an attribute ( factor) affecting the outcome. The relationship between the outcome and the attribute is represented by the decision tree.

Normally, the decision tree comprises of the following: a root, a branch and a leaf. This can be represented by the following example as shown in Figure 1 (Al-Attar 1993):

```
ATTRIBUTE2
|_______________a: ATTRIBUTE1
|                      |__________1: outcome1
|                      |__________2: outcome2
|_______________b: ATTRIBUTE3
                       |__________x: outcome2
                       |__________y: outcome3
                       |__________z: outcome3
```

FIGURE 1. General form of a decision tree

The attributes involved in the decision making task above are ATTRIBUTE1 with values 1 and 2, ATTRIBUTE2 with values a and b, and ATTRIBUTE3 with values x ,y and z. The possible outcomes of the task are outcome1, outcome2 and outcome3. The decision tree represents the logical dependency between the outcomes and the attributes.

## INFERENCE FROM DECISION TREE TASKS

The decision tree structure consists of both decision making knowledge rules and the control rules (or meta-rules) both of which are required to derive decisions. The inference engine executes the sequence of the tree structure from the root to a leaf (outcome).

During inference from the tree, there are two types of processes involved: backward or procedural chaining and forward or sequential chaining. Backward chaining of trees results in a structure of hierarchical decision making tasks. In this process, the inference engine can either prompt the user through the user interface or call another tree whose outcome is the required attribute. These are shown as an example in Figure 2.

```
Decision Task1
      |-----------<-----------Decision Task2
      |                              |----------<-----------Decision Task5
      |                              |----------<-----------Decision Task6
      |
      |-----------<-----------Decision Task3
      |-----------<-----------Decision Task4
```

FIGURE 2. Backward chaining of trees

The above structure implies that in the process of carrying out Decision Task 1, one or more of the Decision Tasks 2, 3 or 4 will be carried out. Furthermore, if Decision Task 2 is carried out then in the process one or more of Decision Tasks 5 and 6 will be carried out.

Forward chaining of trees is the process in which the inference enginereaches a decision from a root tree (the tree at base of the hierarchy) and moves on to derive or infer from another root tree. These can be represented by the example as shown in Figure 3:

```
Decision Task1
      |----------->-----------Decision Task2
      |                              |---------->-----------Decision Task5
      |                              |---------->-----------Decision Task6
      |
      |----------->-----------Decision Task3
      |----------->-----------Decision Task4
```

FIGURE 3. Forward chaining of trees

The above structure implies that Decision Task1 is carried out first and then depending on the outcome, one of Decision Tasks 2, 3 or 4 will be carried out. If Decision Task2 is carried, out then again, depending on the outcome, one of Decision Tasks 5 or 6 will be carried out. The structure can be described as a tree of decision tasks.

## PATTERN RULES REPRESENTATION

A decision making representation task using decision trees can only represent mutually exclusive outcomes. However, there are some conditions in which the outcomes are not mutually exclusive. Pattern rules offer an alternative method of solution as they contain a large number of non-mutually exclusive outcomes. The syntax of pattern rules is shown below:

```
IF condition 1
    AND condition 2
    AND.....
    DO outcome 1. Outcome 2......
```

The output of a pattern rule is a set of actions (outcome 1, outcome 2. etc.).

The inference engine used in pattern rules only executes if the values of all attributes appearing in the task are obtained. i.e values are first scanned against the pattern rules to check for rules which fire (when all the conditions are satisfied). The outcomes (actions) of all fired rules are then executed.

To use pattern rules, a task is defined as having attributes and outcomes. However, while a decision tree task will return one outcome, a pattern rules task will execute the commands attached to all the outcomes selected by the rules, and will then return the 'task' outcome and execute its commands. The 'task' outcome is defined within the Pattern Rules View (i.e. the view for the current pattern rule for an individual task) and is the outcome that is returned by the task regardless of which rules fire. The advantages of this representation are that decision tree and pattern rules are identical in the definition of their attributes and outcomes and in what they ultimately return, one outcome. This enables a pattern rules task to be part of a chained tasks hierarchy (i.e. it can be called as a back chain and it can forward chain to other tasks).

## PROCESS SELECTION METHODOLOGY

In order to arrive at an optimum solution for the selection of an industrial wastewater treatment plant, information is required relating to the problem. In a conventional situation the design engineer would gradually collect, collate and analyse this information in a rational sequence allowing decisions to be made in an ordered and structured manner. It is the skill and experience of the engineer which minimises the data requirement, allowing decisions to be made with minimum expenditure of service support. Inevitably, data and the experience of others will be required in the decision making process and to this end the engineer will undoubtedly require a comprehensive knowledge of pollutant determinants, site and regulatory information, and bibliographic material relating to similar problems. Which, how and when this information is sought is down to the experience of the designer who provides the processing power to interpret and use the information in the decision making process, leading ultimately to a solution.

There are numerous text books on wastewater treatment, most giving adequate, and in some cases, excellent descriptions of the unit processes which can be applied to pollutant removal from aqueous solution. Inevitably these texts deal with each process in isolation and it is rare that information or guidance on "how to string these together" to form a complete process is given. As seen in the introduction there are only a few examples of lead in diagrams and, where these have been encountered, they only marginally help in the decision making process. Information has been built up empirically over the years to a point where for certain situations a solution is accepted as standard practice. This is certainly the case with domestic wastewater treatment where an ordered sequence of unit operations comprising preliminary, primary, secondary, and, possibly tertiary stages are included. Final choices between process alternatives within each stage are determined by a number of factors that are less easy to define or rationalise; the final choice often being the personal preference of the design engineer. There are similar examples in industrial wastewater treatment where sufficient case histories have been documented, however, these are less common and in most cases each industrial site presents a unique situation.

The expert system technique used in this work is a preliminary attempt at capturing the skill, knowledge base and decision making capability of an experienced engineer. To achieve this there are certain fundamental requirements that the system must achieve which can broadly be classified as: user input, rationalisation of data acquisition, data archiving, decision making, justification, error trapping and reporting.

The system has to achieve this within a very restrictive set of rules and programming functions which make it far less able than the human mind it is attempting to mimic. For this reason the program is restricted in its capabilities and represents only a best attempt, within its programming limitations, to meet the above requirements. Additionally, the program structure has built into it the limitations of its creator in terms of knowledge of the decision making processes required for industrial wastewater treatment. Each expert has his/her own approach to process selection and in some cases this may be at variance to the approach adopted within the program.

The conceptual basis of the program is developed from a probable scenario which might be encountered in a real life situation from the moment of initial enquiry to completion of the design/selection task. The sequence of events is shown in a table of actions, reactions and possible outcomes (Table 1) in the manner in which they might be tackled by an expert. The logic and rationalisation, are then interpreted as a basic flow diagram (Figure 4). How that has been transformed within the capabilities of XpertRule is shown in Figures 5a) and 5b).

The program is incomplete in that it does not deal with all the items outlined in Table 1 in terms of actions and outcomes. The program focuses on situations where no effluent treatment plant is currently installed and where the discharge is likely to result in a breach of consent. It is possible that the program could be expanded to consider other problems such as unreliability of existing plant and process economics but these must remain the subject of future work. Similarly, the program assumes that all possible measures have been investigated and implemented so as to reduce the pollutant load at source through waste minimisation or the introduction of cleaner production technology.

## WASTEWATER CHARACTERISATION

Due to its complexity wastewater is difficult, if not impossible, to completely characterise. There are around six million chemicals referred to in the chemical abstracts and to seek confirmation of the presence or absence of such a wide range of potential contaminants is unreasonable. It is however fair to say that waste streams generated under similar circumstances are likely to have similar compositions; therefore, it can be potentially categorised on an industry basis (method 1). Wastewater can also be categorised on the basis of general pollution indicators (method 2) such as suspended solids, volatile solids, non-volatile solids, BOD, COD, oils and greases, metals, total dissolved solids, TOC, VOCs, etc. It could also be characterised on the basis of the contaminants removed by a specific process or group of processes (method 3), for example, it could be said to have settleable material present if the contaminant level were reduced in a settlement process.

TABLE 1. Basic Decision Making Routes in terms of action, reaction, and possible outcomes

| Action | Reaction | Possible Outcomes |
|---|---|---|
| Initial enquiry from client to solve an effluent problem | Meet with client to determine nature of the problem | 1. Breach of consent<br>2. Current system unreliable<br>3. Looking for cheaper alternative |
| Explore the possibilities of solving the problem at source | Introduce waste minimisation practices. Review water usage.<br>Seek alternative "clean technology" production techniques. | Process effluent is of the "best quality" achievable using BATNEEC. |
| Determine which characteristics of the waste are important | a. Check the effluent consent.<br>b. Check the basis of any charging formula in use.<br>c. Consider process limitations of any existing process. | a. List of those determinants considered important by the regulator.<br>b. List of those determinants which influence current cost of disposal.<br>c. List of potentially inhibitory or interfering materials.<br>d. Limits of resilience of existing process to variations in strength, composition, and flow. |
| Characterise the waste water stream. | What are the important characteristics. | 1. Carry out a complete characterisation.<br>2. Carry out a selective characterisation based on those characteristics deemed to be important. |
| Establish a cost base against which capital and running costs can be evaluated | Obtain information from the utility provider on current disposal costs, and any effluent analysis carried out as part of the cost calculation. | 1. Current costs of disposal.<br>2. Possibly data on flows, COD, BOD, SS etc.<br>3. Cost base established in cases where consent is currently met.<br>4. Base line costs against which incurred costs can be added in meeting a consent |

*continued*

TABLE 1. continued

| Action | Reaction | Possible Outcomes |
|---|---|---|
| Determine which elements of the wastewater require treatment to meet a consent. | Cross check characteristics of the wastewater with those of the consent. | 1. List of pollutants requiring removal.<br>2. Treatment not necessary |
| Determine pollutant load of materials of concern | 1. Need to know total flow.<br>2. Need to know variations in flow. | 1. Flow data not available.<br>2. Flows can be ascertained from manufacturing process.<br>3. Need to conduct a flow survey.<br>4. Data available and loads can be calculated. |
| Decide if the pollutants can be removed in a single unit operation or whether multistage operation is required. | Match pollutants to broad range categories of treatment technology. In the case of more than one technology being required need to know sequence. | 1. Single process.<br>2. Multistage process<br>3. Likely sequence of unit operations based on established convention. |
| Deal with each category of treatment process on an individual basis starting with the most probable first category in the sequence. | List the possible treatment alternatives within each category. | List of preliminary, primary, secondary and tertiary treatment methods, possibly useful in the treatment solution. |
| Decide within each category which of the unit processes can be used to meet the specific consent conditions. | Need to know the removal efficiencies of each unit process. | Allows elimination of those processes that will not meet the consent. |

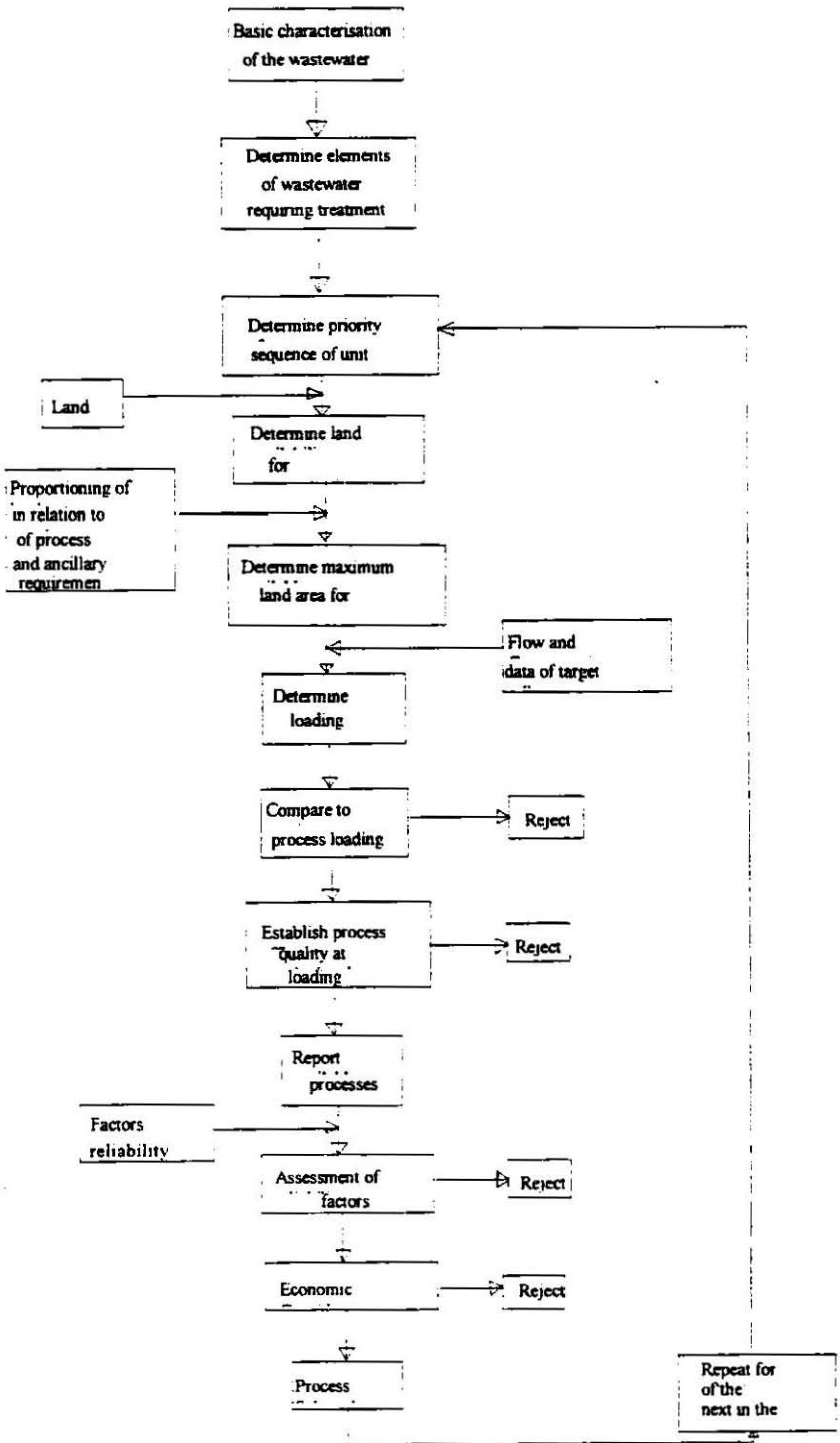


FIGURE 4. Basic flow diagram of the process selection

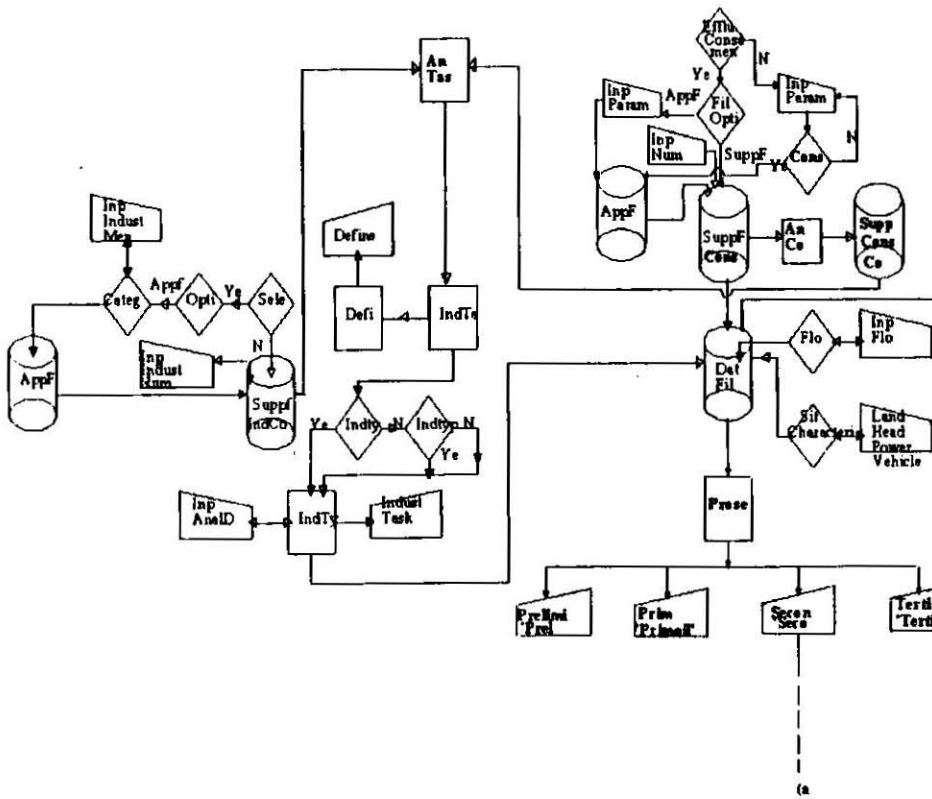


FIGURE 5a. The schematic flow diagram of the program structure for process selection(Rationalisation of wastewater characteristics)

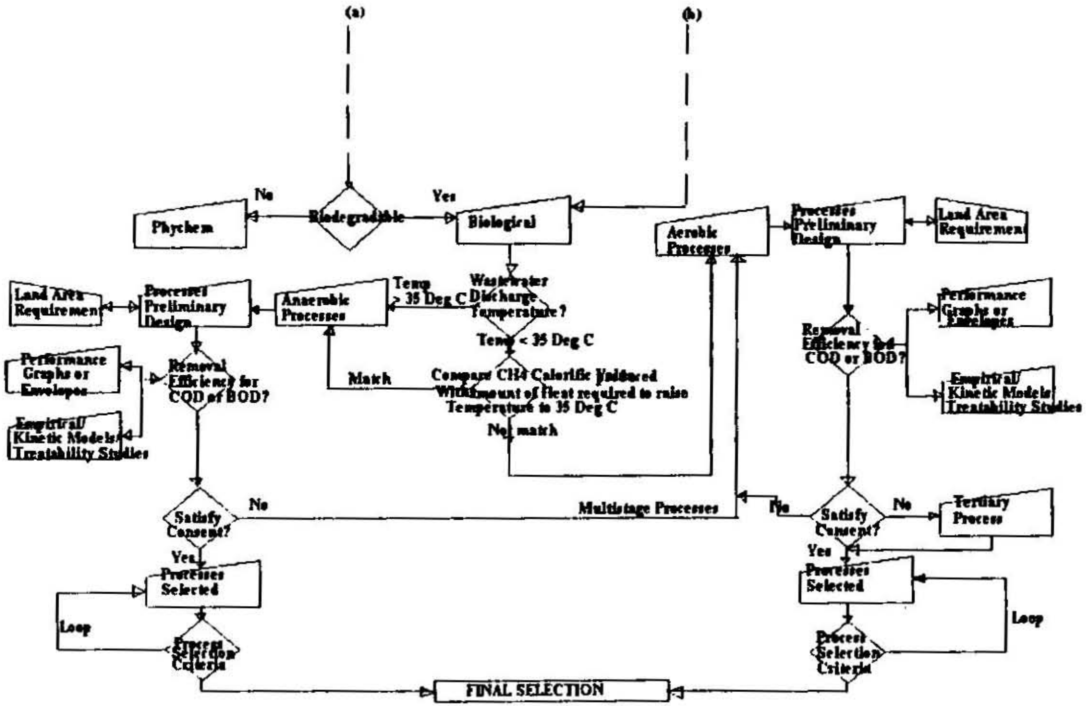


FIGURE 5b. The schematic flow diagram of the program structure for process selection (Biological treatment process alternatives)

Considering the 3 methods of characterisation mentioned above then all have potential advantages and disadvantages but, at first sight, show little commonality. It is apparent that a common starting point is necessary if the selection process is to be rationalised on a computer based system. The concept of waste water categories has been adopted as the common base in this research but programming restrictions required that it was simplified over that suggested by Metcalf and Eddy (1991). The categorisation is based on major properties of the wastewater which are likely to have a high impact on process selection (i.e. method 3). The factors considered are thus the presence of:

1. Coarse solids ( coded as 'CoaSol')
2. Immiscible materials ( coded as 'ImmLiq" )
3. Fine solids particles or sediments ( coded as 'SetSol' )
4. Dissolved organic matter ( coded as 'DisOrg' )
5. Fine suspended or colloidal particles ( coded as 'ColSol' )
6. Metals (coded as 'Metals')
7. Dissolved Inorganic matter (coded as 'Inrogs')

The second potential method of characterisation is to consider that similar industries would produce effluents of similar characteristics (i.e. method 1). Therefore by identifying the major pollutant groups within industry types in line with the 7 characterisation properties, conversion to the common code can be achieved. The general picture of how this can be achieved is shown in Table 2.

TABLE 2. Characterisation of wastewater based on industry type according to the 7 selected characterisation properties

| Industry Categories | Code Group | Primary Composition |
|---|---|---|
| Dairies processing | CoaSol. Immliq. DisOrg | Dissolved organic. mainly protein. fat and lactose |
| Meat and poultry processing | CoaSol. ImmLiq. DisOrg. ColSol. Inorgs | Dissolved and suspended organic; including protein. blood. grease. fats and manure |
| Fruit and vegetable canneries | CoaSol. DisOrg. ColSol | Dissolved and suspended organic from natural products |
| Breweries and distilleries | SetSol. DisOrg | Dissolved and suspended organic |
| Pharmaceuticals | CoaSol. SetSol. DisOrg. ColSol. Metals. Inorgs | Dissolved and suspended organic. including some surfactants and biological agents |
| Organic chemicals | CoaSol. ImmLiq. DisOrg. ColSol. Metals. Inorgs | Dissolved organic. including acids. aldehydes. phenolic. free and emulsified oils |
| Petroleum refining | CoaSol. ImmLiq. SetSol. DisOrg. ColSol. Metals. Inorgs | Phenolic. free or emulsified oils and other dissolved organic |
| Plastics and resins | CoaSol. ImmLiq. SetSol. DisOrg. ColSol. Metals. Inorgs | Dissolved organic. including acids. aldehydes. phenolic. cellulose. alcohols, surfactants and oils |

continued

TABLE 2. continued

| Industry Categories | Code Group | Primary Composition |
|---|---|---|
| Explosives | CoaSol. ImmLiq. SetSol. DisOrg. ColSol. Metals | Organic acids. alcohol. soaps and oils. |
| Rubber | CoaSol. ImmLiq. SetSol. DisOrg. ColSol. Inorgs | Dissolved and suspended organic. and oils |
| Textiles | CoaSol. ImmLiq. SetSol. DisOrg. ColSol. Metals. Inorgs | Dissolved and suspended organic. fats and oils. |
| Leather tanning and finishing | CoaSol. ImmLiq. SetSol. DisOrg. ColSol. Metals | Dissolved and suspended organic. fats and oils. organic nitrogen. metals. hair and fleshing |
| Coke and gas | CoaSol. DisOrg. ColSol. Inorgs | Phenolic. ammonia and dissolved organic |
| Electricity generation | CoaSol. SetSol. ColSol | Solids |
| General engineering (eg. machining) | CoaSol. ImmLiq. SetSol. ColSol. Metals. Inorgs | Oils. greases .solids. cyanide. surfactants |
| Fertiliser | DisOrg. Inorgs | COD. ammonia. phosphate |
| Inorganic chemicals | CoaSol. SetSol. ColSol. Metals | Acids. alkalis. metals |
| Pesticides | DisOrg | COD |
| Mining(coal. mineral) | CoaSol. SetSol. ColSol. Metals | Solids. metals. acids |
| Photographic | CoaSol. SetSol. DisOrg. ColSol. Metals. Inorgs | Metals. sulphur. compounds. acids. alkalis. COD |
| Surface treatment | CoaSol. ImmLiq. SetSol. ColSol. Metals | Acids. alkalis. cyanides. metals. surfactants. oils. grease. solids |
| Wool processing | CoaSol. ImmLiq. SetSol. DisOrg. ColSol | BOD. grease. solids. alkalis |
| Metals plating | Metals | Metals |

The third potential method of characterisation is to consider the general pollution indicators (i.e. method 2). This is achieved by comparing the analytical value against a cut-off value in order to make a determination of a category code group as shown in Table 3.

## SEQUENCING OF UNIT OPERATIONS

The sequencing of unit processes based on the compositional code will be considered as shown inTable 4.

In terms of the methodology being developed and the programming structure the coded compositional sequence relates to this sequencing of processes as indicated in the table above.

TABLE 3. General Pollution Indicators Analysis characterisation

| Input Parameter | Cut-off Values ($> mgl^{-1}$) | Wastewater Characterisation | Code Group |
|---|---|---|---|
| Biochemical Oxygen Demand | 30 | Organically rich | DisOrg |
| Chemical Oxygen Demand | 60 | Organically rich | DisOrg |
| Total Organic Carbon | 60 | Organically rich | Disorg |
| Suspended Solids | 50 | Coarse solids. fine solids | CoaSol. SetSol |
| Volatile Suspended Solids | 100 | Fine solids. fine suspended or colloidal particles | SetSol. ColSol |
| Oil and Grease | 50 | mmiscible materials | ImmLiq |
| Zinc | 35 | Metals laden | Metals |
| Copper | 10 | Metals laden | Metals |
| Nickel | 10 | Metals laden | Metals |
| Lead | 10 | Metals laden | Metals |
| Magnesium | 10 | Metals laden | Metals |
| Cadmium | 0.1 | Metals laden | Metals |
| Cyanide | 2 | Metals laden | Metals |
| Mercury | 0.1 | Metals laden | Metals |
| Silver | 10 | Metals laden | Metals |
| Arsenic | 10 | Metals laden | Metals |
| Aluminium | 10 | Metals laden | Metals |
| Manganese | 10 | Metals laden | Metals |
| Chromium | 10 | Metals laden | Metals |
| Iron | 10 | Metals laden | Metals |
| Nitrate | 50 | Disolved inorganic matter | Inorgs |
| Phosphate | 2.2 | Dissolved inorganic matter | Inorgs |
| Ammonia | 0.5 | Dissolved inorganic matter | Inorgs |
| Sulphate | 1000 | Dissolved inorganic matter | Inorgs |
| Sulphide | 1 | Dissolved inorganic matter | Inorgs |
| Nitrite | 0.1 | Dissolved inorganic matter | Inorgs |
| Chloride | 400 | Dissolved inorganic matter | Inorgs |

TABLE 4. Sequencing of unit processes based on common code characteristics

| Compositional Code | Treatment Stage | Treatment Type |
|---|---|---|
| CoaSol | Preliminary | Coarse solids removal or masceration |
| ImmLiq, SetSol, Metals* | Primary | Gravity separations with or without precipitative, coagulative or flocculative chemical addition |
| DisOrg | Secondary | Oxidation & reduction reactions<br>a. Biological<br>b. Non biological |
| ColSol, Inorgs, Metals* | Tertiary/Advanced | Separation of dissolved non-biodegradable solids, separation of non- settleable secondary solids, further reductions in soluble organic materials. |

*Metals are a special case and removal from a mixed waste stream may be considered at either the primary or tertiary stage.

Also in certain cases, as indicated earlier, primary treatments may be dispensed with if the separated material may be further degraded in the secondary stage. Anaerobic biological treatment is regarded as a secondary treatment as it involves biological reactions which reduce the aqueous and solid phase pollution load.

As far as the user is concerned no further input of data is required for the preliminary process selection and the user will receive a report at the end of the analytical data input section of the user program. Based on the common code characteristics of those materials required to be removed, as determined by comparison of influent wastewater composition and effluent consent, the report will take the following format (assuming all the common code characteristics were present):

| *Common code characteristics* | *Treatment required* |
|---|---|
| CoaSol | Screen |
| ImmLiq | Gravity separation |
| SetSol | Sedimentation |
| DisOrg | Biological oxidation |
| ColSol | Flocculation/Flotation |
| Metals | Tertiary treatment |
| Inorgs | Tertiary treatment |

When there is a requirement for removal of less than the full set of the wastewater categories e.g. only SetSol and DisOrg, only those treatment processes suitable for these would be reported by the program.

## FLOW CHARACTERISATION AND LAND AVAILABILITY

In order to proceed with a more precise process selection it is necessary to know the flow characteristics of the wastewater together with information relating to the site. Flow information is necessary for two main purposes:

1. To calculate the pollutant load.
2. To determine whether equalisation facilities are required or whether batch or continuously operated process plants are most suitable.

The data are required throughout the remaining selection procedure and is thus held in the main data file until required.

From the user of the program it is necessary to find out the total flow and any variation in flow that may take place on a daily basis. Ideally, variations between days. weeks and months should also be known. but these are dealt with as special cases. Flow characterisation can be achieved in a number of ways and ideally should be as the result of a properly conducted flow survey carried out over a representative period. In the preliminary stages of process selection, these data may not be available in this form and the program therefore adopts a more pragmatic approach allowing flow characterisation to be achieved in a sequential manner.

Of importance at this stage in the process is a knowledge of the land area that is available for the construction of the treatment plant. Again, this information is requested early on and stored in the main data file until required throughout the remaining program and selection procedures.

## SELECTION OF SECONDARY TREATMENT PROCESSES

The concepts embodied within this section and the mode of executing these via the computer program are common to the preliminary, primary and tertiary processes. Within the current research these have not been fully developed past the stage of the preliminary reporting.

In order to proceed with secondary treatment process selection a major decision has to be made as to whether treatment should proceed via a biological or physicochemical route.

On entering the values for filtered BOD ($BOD_f$) and filtered COD ($COD_f$) in the secondary treatment report, a subsequent report on the biodegradability of the wastewater will appear on the screen. This is achieved by making an assumption that if $COD_f$ to $BOD_f$ ratio is greater than 3:1 then the wastewater is not considered biodegradable. Likewise, on entering the values for colloidal BOD ($BOD_c$), colloidal COD ($COD_c$), supernatant BOD ($BOD_s$) and supernatant COD ($COD_s$) the secondary treatment report will show whether the wastewater most likely contains organic colloidal solids or not.

Determination of the biodegradability and the presence of organic colloidal solids in the wastewater results in a screen report which indicates whether the wastewater will most likely require a physicochemical or biological process or the combination of both for its further treatment. If it appears that the physicochemical process will be most appropriate for the treatment of the wastewater, a report will be produced as follows:

"Please note: This part of the program is not developed"

This simply means that the system is beyond the scope of this research.

## PRELIMINARY SELECTION TO DETERMINE WHETHER AEROBIC OR ANAEROBIC SYSTEM IS APPROPRIATE

As the user proceeds with the process selection, an input data menu appears on screen which asks the user to insert the temperature of the wastewater discharge ( in°C); this is important in determining whether the wastewater may be suitable for anaerobic treatment as a first stage. If the temperature of the wastewater entered by the user is above 35°C a screen report is generated which says that the wastewater may be suitable treatment via an anaerobic process in the first stage.On the other hand, if the user entry for temperature of the wastewater is below 35°C the program undertakes a further task before the report is generated. A temperature of 35°C was chosen as the cut off point used in the calculation and the above assumption as this is recognised as being the optimum temperature under which high rate mesophilic anaerobic digesters operate (Saw 1988; Metcalf and Eddy 1991). This subsequently task is used to compare between the amount of heat required (in kilocalories) to raise the temperature of the wastewater discharge to 35°C and the amount of heat generated (in kilocalories) by means of the conversion of COD into methane gas. The amount of heat required and the amount of heat generated are calculated using the equations as follows:

Amount of heat required ( in Mcal) = Wastewater feed volume ($m^3$) x Temperature rise (°C)

Amount of heat generated ( in Mcal) = COD($kgm^{-3}$) x Wastewater Flow($m^3$) x 3 °C

Both the heat required and generated equations result in the cancellation of wastewater flow and eventually yield the general equation for the calculation of heating potential of methane gas generated, which will be used later in the program structure. The equation used is shown below:

Heating potential of methane generated = 0.7 x Total COD (kg/d)

At this point, it is not known how much of the COD of the influent would be converted to methane in the digestion process. As most high rate anaerobic digestion processes show conversion in the range of 50 to 90% depending upon the loading, a conversion efficiency of 70%(midpoint) has been included in the calculation; this was thought to be a satisfactory estimate for the present purpose of preliminary process selection. It may also be necessary at this stage to calculate the heat loss from the reactor which can be achieved, at this point, after a preliminary sizing of the vessel has been made. The equation employed would be as follows (Metcalf and Eddy 1991):

$$q = UA\Delta T$$

where $q$ = heat loss, W or J/s
$U$= overall coefficient of heat transfer, W/$m^2$ °C
$A$ = cross-sectional area through which the heat loss is occuring, $m^2$
$\Delta T$=temperature drop across the surface in question, °C

As a result of these last two calculations, a process could be rejected as this stage and if all the available anaerobic processes were rejected the program could be made to revert automatically to an aerobic selection route.

AEROBIC AND ANAEROBIC PROCESS SELECTION

Both the aerobic and anaerobic process selection routes are mirror images as far as the tools and program methodologies used are concerned. The steps involved are:

*Calculation of Biological Reactor Size* All the information required is embedded in the data file and will eventually be used in the preliminary design of the system. The information enables the program to determine the volume of the reactor for each process within the limits of acceptable volumetric loading rates.

$$\text{Volume of reactor } (m^3) = \frac{\text{Flow rate } (m^3d^{-1}) \times \text{ Inlet COD}(kgm^{-3})}{\text{Volumetric loading rate } (kgm^{-3}d^{-1})}$$

*Calculation of Footprint Area for the Reactor* The equation used to calculate the minimum surface area requirement for the reactor is as follows:

$$\text{Surface Area Required for reactor } (m^2) = \frac{\text{Volume of reactor } (m^3)}{\text{Max depth of reactor } (m)}$$

*Calculation for Secondary Sedimentation and Sludge Processing Tanks* Surface area of secondary sedimentation tank can be calculated using the formula as follows:

$$\text{Surface area required for the tank} = \frac{\text{Wastewater flowrate } (m^3/d)}{\text{Overflow rates } (m^3/m^2.d)}$$

The surface area of the sludge processing tanks was calculated on the sludge yield and % dry solids of the respective process. From a knowledge of the net sludge yield and values of the influent BOD and flowrate, the quantity (kg/d) of sludge is calculated using the following equation:

$$\text{Dry solids production } (kg/d) = \text{Wastewater flow } (m^3/d) \times \text{BOD } (kg/m^3) \times \text{net yield coefficient.}$$

It is also known that sludges from different processes have different characteristics especially in relation to their water retaining qualities. Knowing these likely concentrations allows calculation of the wet sludge volume:

$$\text{Wet Sludge Volume} = \frac{\text{Dry solids production } (kg/d)}{\text{Typical solids content } (kg/m^3)} = \text{Volume } (m^3/d)$$

*Calculation of Flow Balancing Tank* For the purpose of preliminary process selection, the sizing of a flow balancing tank on the above assumptions was thought to be satisfactory.The method involves tabulating the cumulative flows for hourly time intervals over a suitable time period in which flow variations may be apparent. The data is then plotted as a cumulative flow volume. A line is then drawn from the origin to the end point of the inflow mass diagram. the slope of which represents the average flowrate for the chosen time period. To determine the required volume, a second line is drawn parallel to the average flowrate tangent intersecting the low point of the inflow mass diagram. The required volume is represented by the vertical distance from the point of tangency to the straight line representing the average flowrate.

## CALCULATION OF THE OVERALL LAND AREA REQUIREMENT

The land area requirement can be determined by the general formula as follows:

Land area requirement ($m^2$) = Reactor Area + Primary Sedimentation Tank Area + Flow Balancing Tank Area + Secondary Sedimentation Tank Area + Sludge Processing Tank Area

## REPORTS RELATING TO PRELIMINARY BIOLOGICAL PROCESS SELECTION PROCEDURE

The calculated land area requirement is then compared with the available land area embedded in the main data file. If the land area required is less than the land area available, then the process will most likely be selected. On the other hand, the process will be rejected if the land area required is greater than the land area available at the proposed site.

## FINAL SELECTION OF BIOLOGICAL TREATMENT OPTION

Again the aerobic and anaerobic routes are mirror images and will be dealt with together. The only exception to this is where a multistage (anaerobic/aerobic) process may be required.

For refinement of the preliminary selection it is necessary to compare the calculated volumetric loading to the acceptable loading rate that will guarantee acceptable process effluent quality, this is particularly true of what are regarded as being "high rate processes". It is therefore necessary to check for each acceptable loading that an acceptable effluent is achieved at the calculated loading. This can be done in one of three ways:

1. By calculation based on an acceptable kinetic model for the process
2. By reference to empirical performance data from an established plant
3. By conducting laboratory or pilot scale experiments.

The reliability, accuracy and applicability of each of these methods need to be fully established by further research.

A preferred option, as far as the methodology being developed is concerned, would be to establish, as part of the knowledge base, a performance envelope for each of the processes included. A performance envelope looks at the target parameter as a loading factor and predicts (within the limits of the envelope) the final effluent quality. Thus for any process loading the worst, the best and the average effluent quality can be established empirically. Removal of secondary pollutants (non target) could exist (or has not been added to the knowledge base) option 3 could be resorted to or literature reviewed so as to enhance the knowledge base. Processes which would not give the required process effluent standard can be rejected at this point.

## ESTABLISHMENT OF PERFORMANCE GRAPHS OR ENVELOPES

For each of the biological processes included within the selection procedure, process performance envelopes have been derived based on existing data from the literature as shown in Figures 6 through 17 which further give the results as shown in Table 5:

TABLE 5. Summary of the results obtained from the performance envelopes

| Figure No. | Total number of points | Percentage of points in 10% band | Percentage of points in 20% band | R square | Slope of the graph | Y intercept |
|---|---|---|---|---|---|---|
| 6 | 15 | 86.67 | - | 0.52 | 1.67 | 97.2 |
| 7 | 17 | 76.47 | - | 0.05 | 1.12 | 60.4 |
| 8 | 48 | 100.00 | - | 0.72 | 0.54 | 102.1 |
| 9 | 44 | - | 81.82 | 0.48 | 1.99 | 76.4 |
| 10 | 23 | - | 78.26 | 0.64 | 3.32 | 101.3 |
| 11 | 59 | 79.66 | - | 0.03 | 0.24 | 75.2 |
| 12 | 28 | 96.43 | - | 0.80 | 0.74 | 94.7 |
| 13 | 22 | 77.27 | - | 0.05 | 1.85 | 53.9 |
| 14 | 9 | 100.00 | - | 0.55 | 2.12 | 91.9 |
| 15 | 46 | - | 73.91 | 0.62 | 3.17 | 91.4 |
| 16 | 75 | 97.33 | - | 0.79 | 38.97 | 96.5 |
| 17 | 13 | 92.31 | - | 0.23 | 11.87 | 85.3 |

The results of this preliminary data analysis are discussed below.

Table 5 concludes that Figures 8, 12 and 16 are considered to have a good performance data because their R square ($R^2$) or regression coefficient values are greater than 0.7. Figures 6, 10, 14, and 15 are considered to have a fair performance data because their $R^2$ values are between 0.5 to 0.7. Figures 7, 9, 11, 13 and 17 are considered to have a poor performance data as their $R^2$ values are below 0.5. Based on the results shown in Table 5, it can be concluded that there are only three sets of data (i.e. Figures 8, 12 and 16) which show a high quality data abstracted from the literatures. The others are considered as fair or low quality data which require further justifications as to the validity of the data in the form of a treatability study.

A performance envelope is only as good as the data it contains, and in some cases the spread of data points is greater than would be ideal. For each set of performance data the line of best fit was established by linear regression; in most cases this showed a better fit to the data than other forms of regression, it was therefore applied universally. The advantage of a linear regression was that the slope of the line could easily be determined and used as a single input into

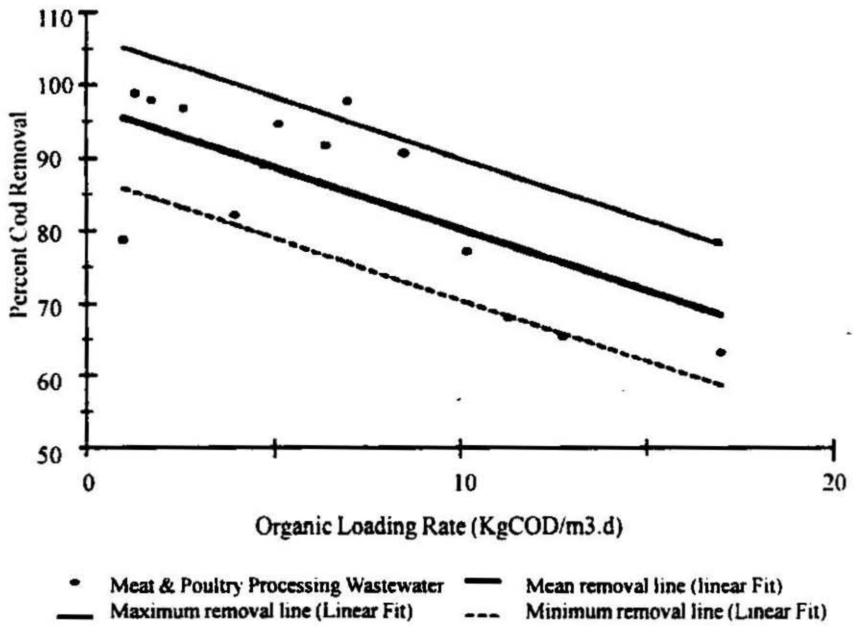


FIGURE 6. Organic Loading Rate Vs % COD Removal for UASB Reactor treating Meat & Poultry Processing Wastewater

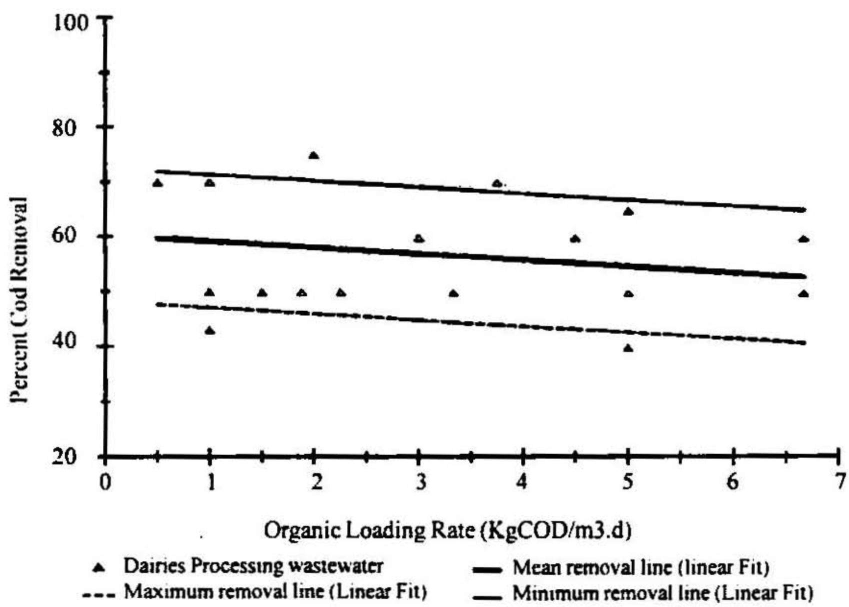


FIGURE 7. Organic Loading Rate Vs % COD Removal for UASB Reactor treating Diary Processing Wastewater

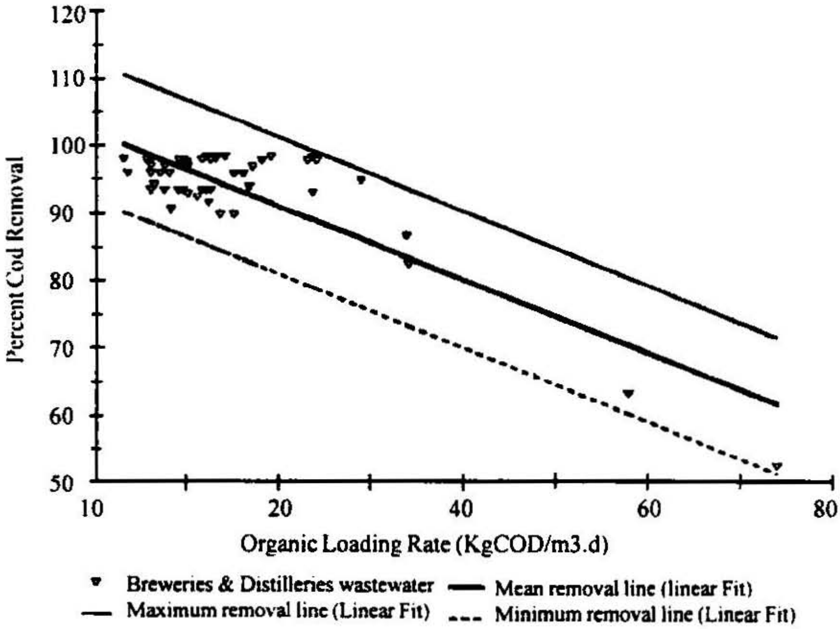


FIGURE 8. Organic Loading Rate Vs % COD Removal for Anaerobic Fixed-Bed Reactor treating Brewery and Distillery Wastewater

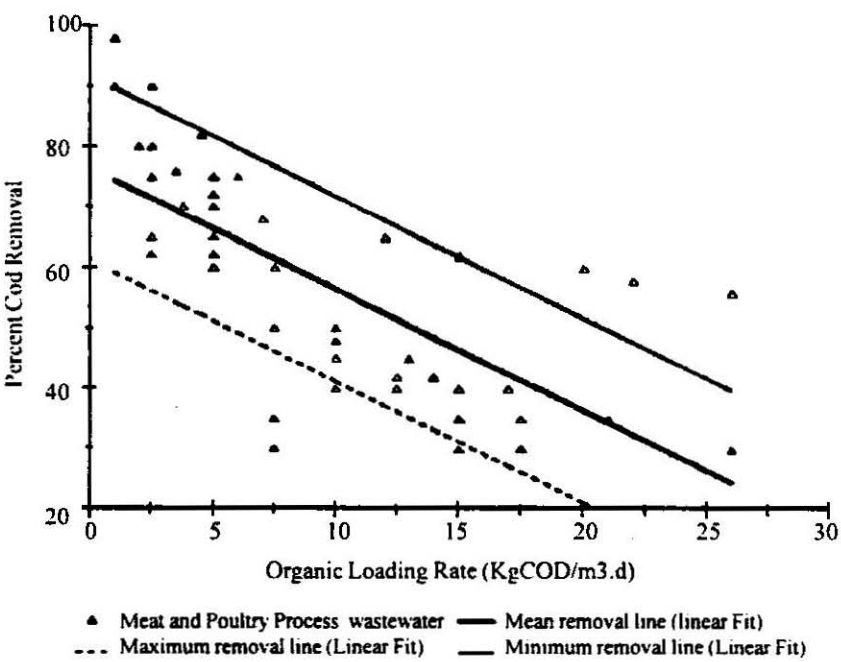


FIGURE 9. Organic Loading Rate Vs % COD Removal for Anaerobic Fixed-Bed Reactor treating Meat & Poultry Processing Wastewater

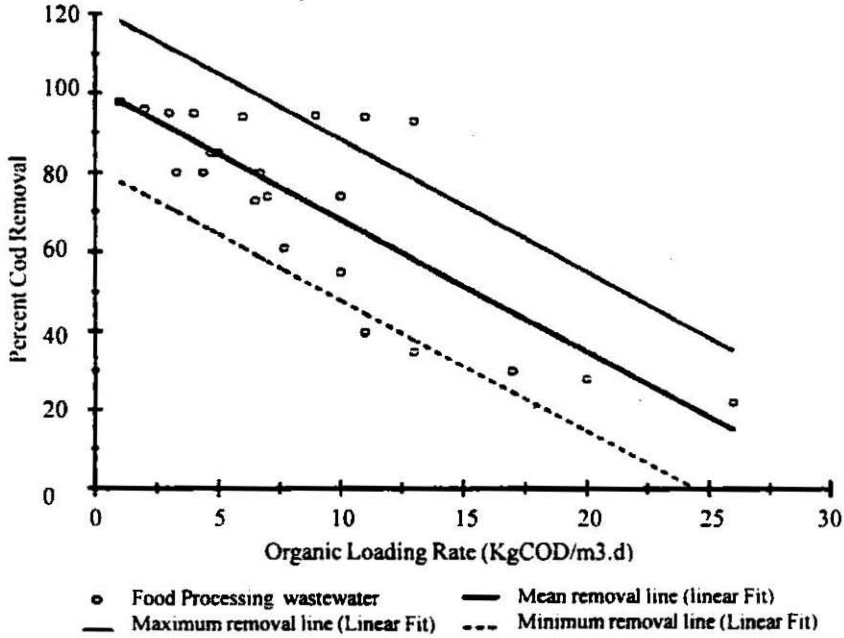


FIGURE 10. Organic Loading Rate Vs % COD Removal for Anaerobic Fixed-Bed Reactor treating Food Processing Wastewater

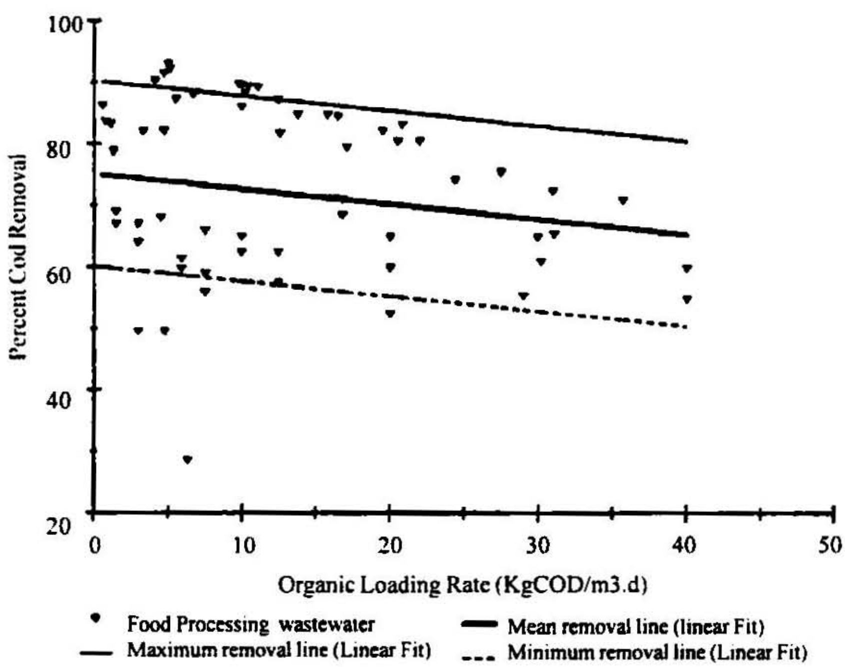


FIGURE 11. Organic Loading Rate Vs % COD Removal for Anaerobic Fluidis-Bed Reactor treating Food Processing Wastewater

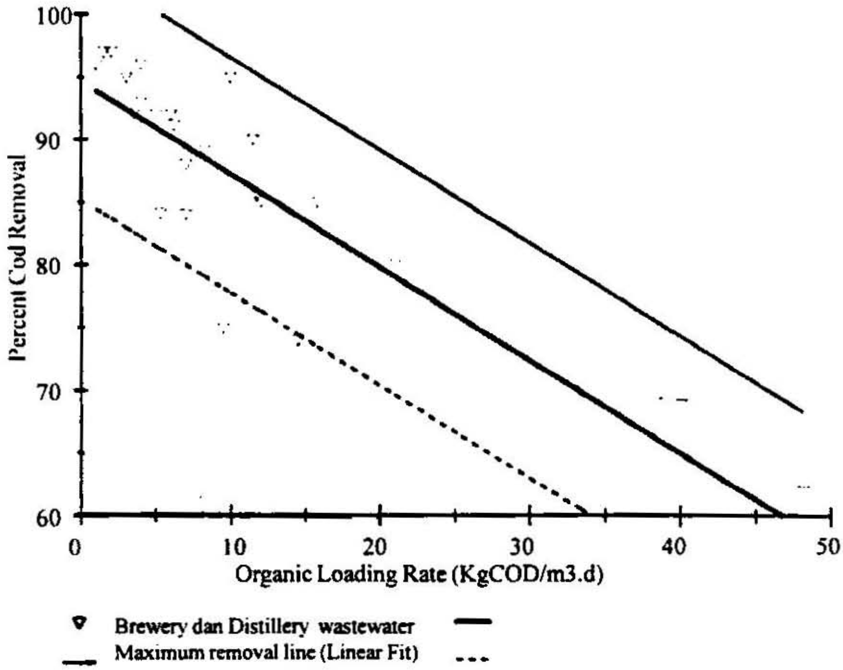


FIGURE 12. Organic Loading Rate Vs % COD Removal for Anaerobic Fluidis-Bed Reactor treating Brewery & Distillery Processing Wastewater

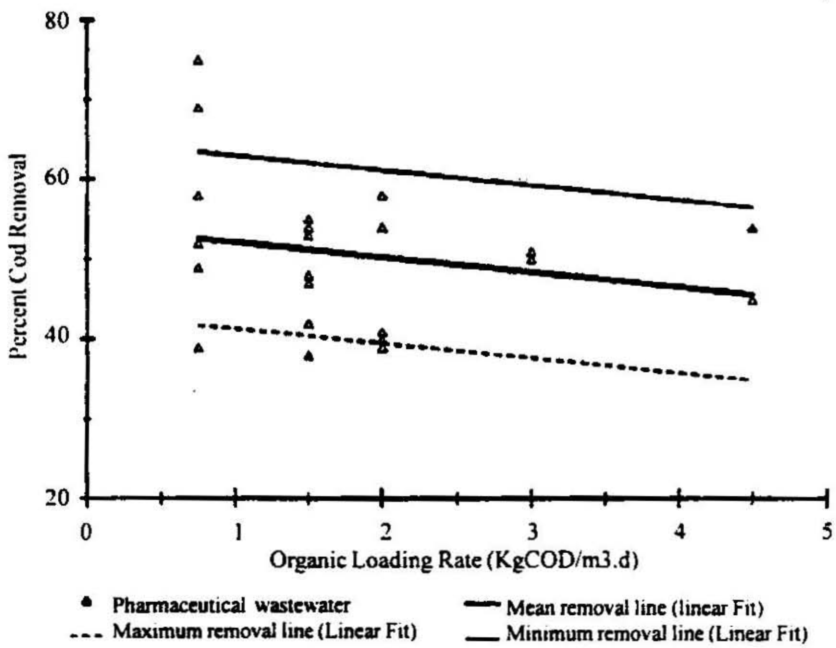


FIGURE 13. Organic Loading Rate Vs % COD Removal for Anaerobic Fluidis-Bed Reactor treating Pharmaceutical Processing Wastewater

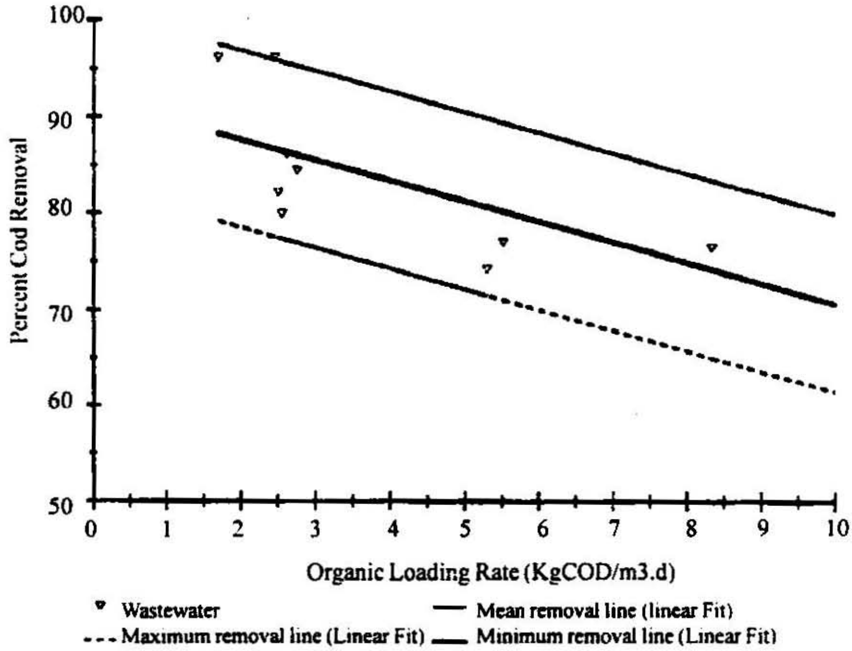


FIGURE 14. Organic Loading Rate Vs % COD Removal for Anaerobic Contact Process treating Brewery, Ice-cream. Wheat-starch. Beef- Processing, Olive Mill and Citric Acid Wastewater

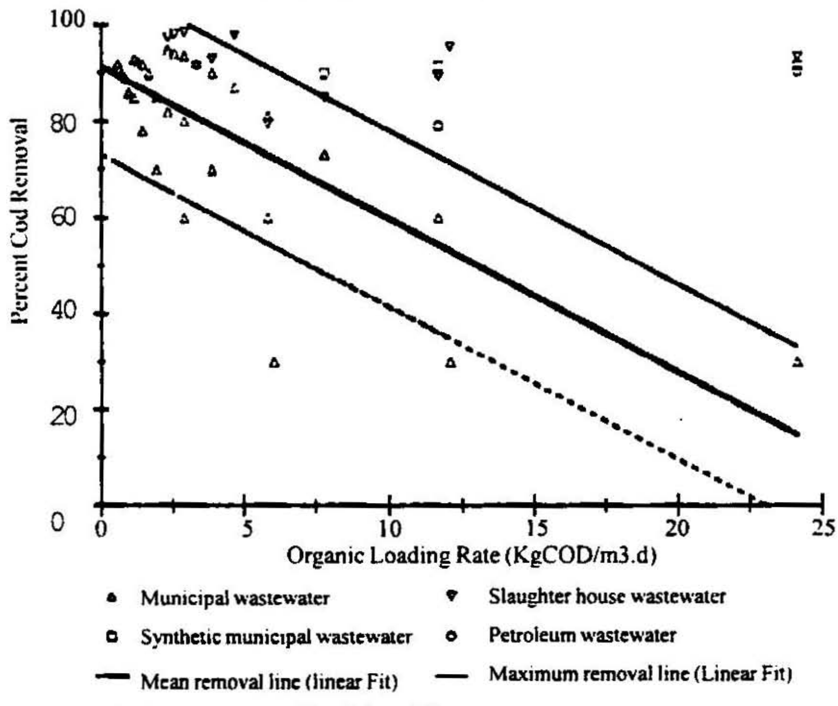


FIGURE 15. Organic Loading Rate Vs % BOD Removal for RBC Units treating Municipal Wastewater. Slaughter Wastewater. Synthetic Municipal Wastewater. Petroleum Wastewater

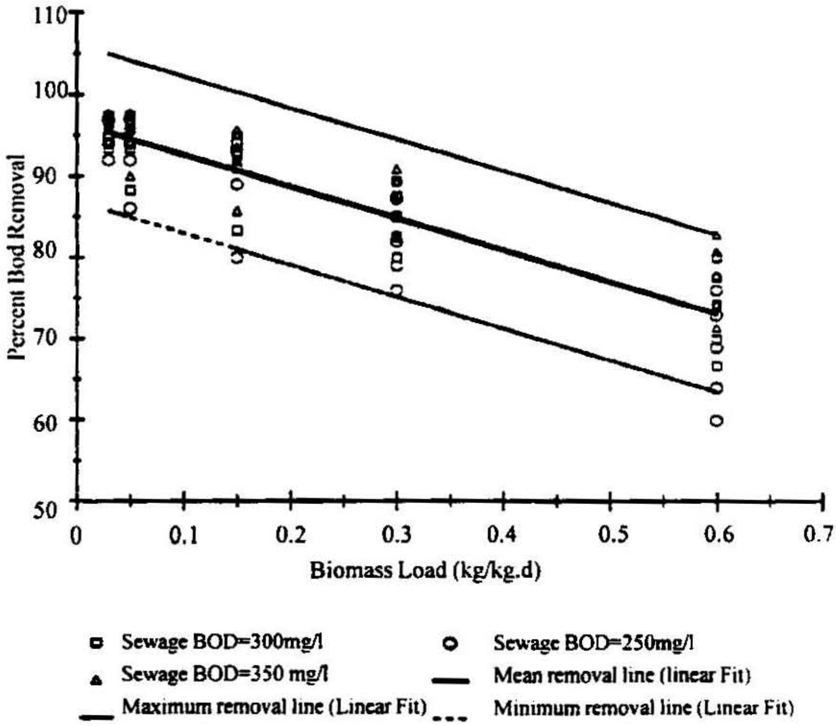


FIGURE 16. Biomass Loading Rate Vs % BOD Removal for Activated Sludge Processes treating Sewage

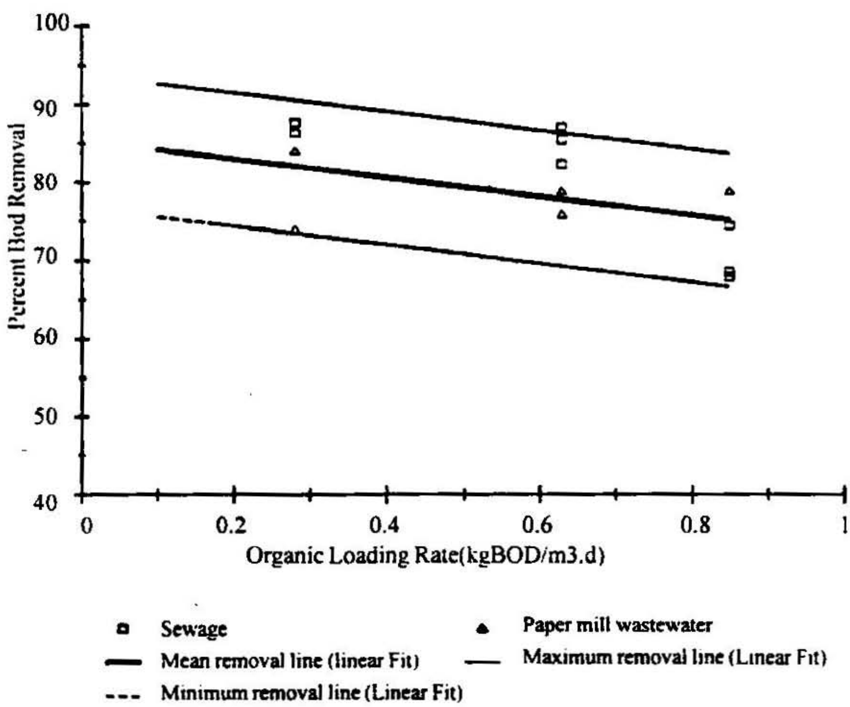


FIGURE 17. Organic Loading Rate Vs % BOD Removal for Trickling Filters treating Sewage and Paper Mill Wastewater

the XpertRule program. This is one of the reasons why the linear interpretation of the data is needed so as to enable XpertRule program (within its limitation) to use the data for further calculations. As mentioned earlier, to check on variance of the data used in calculating the performance line, parallel lines were constructed at + and - 10% or 20% removal efficiencies and the number of data points encapsulated within the resulting envelope calculated as a percentage of the total. The reason for doing this and not relying upon the regression coefficient was to identify groups of abnormal data points which may have originated, possibly, from an atypical study.

The performance line (envelope) is designed to be dynamic and add to the knowledge base encapsulated within the program. It is therefore essential that new information can simply and easily be added, including data from treatability studies specifically run for the case in question. For this reason a standard spreadsheet package "Excel" was chosen as the data entry and processing platform.

## UTILISATION OF PERFORMANCE DATA IN THE PROCESS SELECTION METHODOLOGY

Data from the performance graphs is used to determine the minimum volumetric loading rate required to achieve the final effluent quality of the wastewater for each selected process. This can be generalised by the following equations:

$$\frac{\text{BODin (mgl}^{-1}\text{)- BODout (mgl}^{-1}\text{)x100}}{\text{BODin (mgl}^{-1}\text{)}} = \text{(Slope x Volumetric load rate (kgm}^{-3}\text{d}^{-1}\text{))} + \text{(Intercept)} \quad (1)$$

$$\frac{\text{CODin (mgl}^{-1}\text{)- CODout (mgl}^{-1}\text{)x100}}{\text{CODin (mgl}^{-1}\text{)}} = \text{(Slope x Volumetric load rate (kgm}^{-3}\text{d}^{-1}\text{))} + \text{(Intercept)} \quad (2)$$

$$\text{Volumetric load rate (kgm}^{-3}\text{d}^{-1}\text{)} = \frac{\dfrac{\text{(Intercept)-(BODin (mgl}^{-1}\text{)-BODout (mgl}^{-1}\text{x100)}}{\text{(BODin (mgl}^{-1}\text{))}}}{\text{Slope}} \quad (3)$$

$$\text{Volumetric load rate (kgm}^{-3}\text{d}^{-1}\text{)} = \frac{\dfrac{\text{(Intercept)-(CODin(mgl}^{-1}\text{)-CODout(mgl}^{-1}\text{)x100)}}{\text{CODin (mgl}^{-1}\text{)}}}{\text{Slope}} \quad (4)$$

The slopes and intercepts above are calculated based on the equations as described by Edwards (1976). He states that a linear graph can be represented by a very simple expression as follows:

$$y = a - bx$$

where $a$ = $y$-intercept
$b$ = slope of the graph

The slope of the graph, $b$ can be calculated by the following expression:

$$b = \frac{\Sigma (X^*Y) - \dfrac{(\Sigma X)^* (\Sigma Y)}{n}}{\Sigma X^2 - \dfrac{(\Sigma X)^2}{n}}$$

where $X$ = Total in x-axis
$Y$ = Total in y-axis
$n$ = Number of entry (counter)

The $y$-intercept, $a$ can be calculated using the following equation:

$$a = Y\text{bar} - bX\text{bar}$$

where $Y$bar = Average of $Y$
$X$bar = Average of $X$

Both the equations 3 ( aerobic process) and 4 (anaerobic process) are used to determine the minimum volumetric loading rate required to achieve the final effluent consent. Once the VLR is obtained from these equations, the reactor volume and footprint size, including the secondary sedimentation and sludge processing tanks, are then calculated. Based on this information, the process will be accepted or rejected on the basis of land availability.

If there is, in any circumstances, no data available for the establishment of performance graphs or envelopes then the user is prompted to carry out a treatability study in the laboratory in order to gather relevant information in terms of the BOD or COD removal efficiencies for the selected processes. The above methods, again, will have to be carried out sequentially in an attempt to reduce superfluous data at the end of the process selection procedure.

## MULTISTAGE PROCESSES

Multistage process selection is used to couple the predicted effluent parameters from one process to the influent parameters for a second process. The programming techniques applicable to this have been developed in relation to the use of aerobic polishing of the effluent from an anaerobic process as this is important in coupling the split aerobic/anaerobic routes together. The programming techniques are also applicable to other situations where multistage operation may be required e.g. secondary processes to tertiary processes but the codes have not been written for these within the current work.

## COUPLING OF ANAEROBIC TO AEROBIC PROCESSES AS PART OF A MULTISTAGE PACKAGE

Equation 4 is used in order to determine whether the wastewater requires a single stage process or a multistage process. If the calculated VLR (kgCODm$^{-3}$d$^{-1}$) does not able to achieve the final effluent consent, it appears that a multistage process is deemed necessary. Thus, equation 3 will be used to complete the objective, sequentially. As a result, two sequential processes will be required for the treatment of wastewater, i.e. an anaerobic process followed by an aerobic process.

# CONCLUSIONS

The results of the project in relation to its initial aims can be summarised:

1. The methodology developed is of a hierarchical type and this has been shown to minimise the requirement for user input and to avoid the collection of superfluous information relating to the composition of the influent waste water.

2. The project has proven that the methodology can be incorporated into a knowledge based system. All the decision making techniques used by XpertRule have been incorporated into the program and been shown to be useful, although in some cases have extensive chaining operations for simple decision making tasks. The system is thus available to a wide number of users although its justification procedures need to be refined to give more explanation to the user as to how and why decisions were reached.

3. An attempt has been made to produce a standardised data set of 25 analytical parameters. This may prove to be inadequate on verification of the model but can easily be modified as the system requires.

4. The system appears to be easily expandable and should be able to carry out preliminary design tasks.

5. The methodology has been driven by the requirement to meet a desired effluent quality irrespective of the costs likely to be incurred in doing this. Cost considerations need to be developed and included in the final methodology but are regarded as being secondary to quality considerations and ultimately were outside the scope of this study.

6. The methodology appears unbiased towards any single or combination of treatment options. It is however biased in its assumption that in a sequence of operations there is an established order and that is taken to be that used in municipal treatment plants.

7. No work has been undertaken on verification yet it is appreciated that this is essential and must be considered in the future work.

## RECOMMENDATIONS FOR FUTURE WORK

Based on the current study, some recommendations can be made for future work as follows:

1. To make the program capable of carrying out conceptual design tasks for process selection in the preliminary, primary, secondary (i.e. physicochemical processes) and tertiary stages.

2. To expand the existing performance data in the Excel file by adding new data taken from literature/existing plants or carrying out treatability studies in the laboratory.

3. To further refine all of the assumptions made concerning the default values used in the conceptual design tasks within the program so as to enable process selection to be carried out for any given situation.

4. To incorporate process economics within the program in terms of capital, construction, operating and maintenance costs.

5. To verify the model using previous case histories of existing plant.

6. To verify as to whether the methodology adopted in the current work can be applied to a wide range of wastewater types.

7. To explore the possibility of interfacing other windows applications with XpertRule, as an external program, so as to exploit its full potential as a tool for carrying out detailed design tasks for process selection.

8. To consider replacing XpertRule as the processing platform by a custom designed processing package written in a high level computer programming language.

REFERENCES

Adams, P. 1994. Wastewater treatment : Getting it right technically and economically, in wastewater management for industry, IBC Conference Proceedings, 11-13 October 1994. Manchester, U.K.

Al-Attar, A. 1993. Structured decision tasks methodology for developing and integrating knowledge-based systems. Lancashire: Attar Software Ltd pp 72.

Belhateche, D. H. 1995. Choose appropriate wastewater treatment technologies. Chemical Engineering Progress. August 1995, 32-51.

Chia, S. S. & Krishnan, P. 1969. Dynamic optimization for industrial waste treatment design. *Journal of Water Pollution Control Federation* 41: 1787-1802.

Edwards, A. L. 1976. An introduction to linear regression and correlation, San Francisco: W.H. Freeman & Company.

Ellis, K. V. & Tang, S. L. 1991. Wastewater treatment optimisation for development world. 1-Model development. *Journal of Environmental Engineering* 117(4): 501-517.

Evenson, D. E., Orlob, G. T. & Monser, J. R. 1969. Preliminary selection of wastewater treatment systems. *Journal of Water Pollution Control Federation* 41: 1845-1858.

Feigenbaum, E. A. 1982. *Knowledge engineering in the 1980's*. Dept. of Computer Science, Standford University, Standford, California, USA.

Finn, G. A. 1989. Application of expert systems in the process industry, pp. 167-192 in *Dynamic modelling and expert systems in wastewater engineering*, edited by Patry, G.G., and Chapman, D., Chelsea: Lewis Publishers.

Galil, N., Levinsky, Y. 1991. Expert support system for cost modeling and evaluation of wastewater treatment. *Water Science & Technology* 24 (6): 291-298.

Giarratono, J. C. & Riley, G. 1989. *Expert systems: Principle and programming*. Boston: PWS-KENT publishing.

Jackson, P. 1990. *Introduction to expert systems*, Second Edition, Addison-Wesley.

Kao, J. J., Brill Jr, E. D., Pfeffer, J. T. & Geselbracht, J. J. 1993. Computer-Based environment for wastewater treatment plant design. *Journal of Environmental Engineering* 119 (5): 931-945.

Metcalf & Eddy 1991. *Wastewater engineering: Treatment, disposal and reuse*. Third Edition, revised by Tchobanoglous, G., Burton, F., New York: McGraw-Hill pp 1.

Okubo, T., Kubo, K., Hosomi, M. & Murakami, A. 1994. A knowledge-based decision support system for selecting small-scale wastewater treatment processes. *Water Science & Technology* 30 (2): 175-184.

Saw, C.B. 1988. Anaerobic Digestion of Industrial Wastewaters and Municipal Solid Wastes - A Position Study. Report No. LR 672 (MR), Warren Spring Laboratory, Hertfordshire, U.K.

Spinos, M. & Marinos-Kouris, D. 1992. Integrated computer aided process design of wastewater treatment plants on a PC system. *Water Science & Technology* 25 (1): 107-112.

Tang, S. L. & Ellis, K. V. 1994. Wastewater treatment optimization model for developing world: Part II - Model Testing. *Journal of Environmental Engineering* 120 (3): 610-624.

Young, P. W. 1990. Requirements for full or partial treatment of effluents and options available. in wastewater management for industry. *IBC Conference Proceedings*. 27-29 November 1990, Manchester. U.K.

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