Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

DEVELOPMENT OF A PROTOTYPE PORTABLE ADSORPTION UNIT FOR THE TREATMENT OF TOXIC CHEMICAL SPILLS

A thesis presented in partial fulfilment
of the requirements for the degree of
Master of Technology at Massey University

- by -
Matthew William Hynes
1995

ABSTRACT

The use of Carbon Adsorption Technology for the development of a Prototype Portable Carbon Adsorption Unit was investigated. Carbon adsorption is a well-established treatment process. It is much safer and more economical in comparison with other conventional neutralisation techniques used for toxic chemical spill clean up. This thesis begins by examining the nature of toxic chemical spills, the effects on the environment and the economy, and the currently available response methods and treatment technologies. The discussion then continues into the use of Carbon Adsorption Technology for the treatment of toxic chemical spills. This is further developed by the conceptual design of a portable adsorption unit. Small scale column experiments were carried out in order to determine the flow configuration to be adopted by the unit. These experiments showed that an upflow configuration had greater potential to increase adsorption efficiency. From the conceptual design stage a full detailed design of the unit was done from which the unit was constructed. The constructed prototype portable adsorption unit was then evaluated by performing a series of adsorption experiments on a single column. The conclusion reached is that Carbon Adsorption Technology can be successfully applied on a small scale for the treatment of toxic chemical spills.

ACKNOWLEDGMENTS

This thesis concludes many hours of reviewing literature, carrying out experiments and design trialing. I sincerely thank all those people who were involved in this project, from those who shared their knowledge and experience, to those who were involved in the final conception of the adsorption unit.

My thanks to Dr Rao Bhamidimarri, my supervisor, for guiding me through my postgraduate studies, and to both the Department of Process and Environmental Technology for support and assistance. Special acknowledgment must be given to ACC who granted financial assistance for the realisation of this project.

Special thanks goes to Don McClean and John Alger for their help, advice and expertise in the construction of the adsorption unit. I would also like to acknowledge and thank John Seebach from Denmark who dedicated many hours to helping me with the initial experiments and designs.

Finally, I wish to thank my wife, Judith, for her unending patience, support and help.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

INTRODUCTION

The pollution of the environment and safety and health risk to personnel due to accidental spills of agricultural and industrial toxic chemicals is frequent. For example, the New Zealand Fire Service attended 2151 and 2708 hazardous substance emergencies in 1990 and 1991 respectively (N.Z. Yearbook, 1990 & 1991). In New Zealand, toxic and hazardous substances may include pesticides, heavy metals, organic compounds and other substances, such as halogenated hydrocarbons and carbon monoxide.

Since New Zealand is basically an agricultural economy, the use of pesticides and herbicides is widespread. For example, up until mid 1988, 200 tonnes of Pentachlorophenol (P.C.P.) were used each year in New Zealand, mainly in protecting sawn timber from fungal attack. It was also used domestically - being available off the supermarket shelf for such things as moss and algae control, used by farmers for home treatment of timber, and industrially to control slime in pulp and paper production, in cooling waters, and in mushroom culture as a soil and timber steriliser.

The spillage of these chemicals during formulation, distribution and application occurs in small amounts, but the aggregate of these small amounts is substantial. A survey conducted by Pacific Basin Hazardous Research reported that there is substantial quantities of unmanaged agricultural waste in New Zealand. In fact, New Zealand keeps no official statistical record on the importation, production or sales of pesticides (Stevenson, 1992). This waste is believed to be disposed of to municipal landfill sites. These landfills are typically not well-managed and offer little protection to nearby natural water, therefore, creating a health risk and causing destruction to aquatic life.

Often chemical spills are promptly diluted and flushed into effluent streams or dispersed into the environment. While being quick, easy and economical in the short term, the end result all to often ends in some form of environmental damage which generally results in very expensive redemption costs, for example, on average each U.S. Superfund site costs $US26 million to clean up (Stevenson, 1992).

There are several technologies available to deal with toxic chemical spills. Of these technologies carbon adsorption is a well-established treatment process. It is much safer and more economical in comparison with other conventional neutralisation techniques used for toxic spill cleanup. In fact, the Environmental Protection Agency in the United States of America maintains a very large adsorption unit for emergency cleaning of toxic chemical spills. Since the processing and application of toxic chemicals in New Zealand is on a much smaller scale and is so widely dispersed, a small scale adsorption unit was proposed as an ideal alternative to the management of toxic chemical spills.

1 CHEMICAL SPILLS, EFFECTS, RESPONSE METHODS AND TREATMENT TECHNOLOGIES

1.1 Definitions

Toxic and Hazardous Substances

Toxic and hazardous substances are defined as substances that have the potential to impair human, plant or animal health, or adversely affect the safety of the environment (Ward J.C. & Beanland R.). These substances exhibit one or more of the following properties (Code of Federal Regulations, 40 CFR Sub part C).

Corrosive	pH less than 2.0 or greater than 12.5.
Ignitable	Peusky-Martens Closed Cup Flash Point of less than 60°C.
Reactive	Thermal or mechanical or chemical reactivity.
Toxicity	Poisons, Carcinogens, Teratogens and Mutagens.

Substances exhibiting one or more of these properties are considered hazardous, and in the United States of America their treatment, storage and disposal are regulated by the Environmental Protection Agency.

Spillage

Spillage is defined as the loss of containment.

1.2 Causes of Toxic Hazardous Spills

The primary causes of hazardous substance spills can generally be fitted into one of five categories:

1) Spills resulting from rupture of or leakage from a storage or transporting container.

2) Spills resulting from the failure of storage, transfer, or transporting equipment.

3) Spills resulting from an in-plant or transportation accident.

4) Spills resulting from personnel error in loading or unloading operations or other improper handling.

5) Spills resulting from intentional events such as vandalism, sabotage, or deliberate release.

A private market survey was conducted by the Ansul Company in the United States to determine the frequency and average size of hazardous material spills in industry. From the 1800 responses from food and beverage industries to petroleum and petrochemical industries, the average spill size was determined to be 50.05 litres and the frequency of spills was determined to be 8 spills per plant per year. The locations in each plant where the spills occurred are illustrated in Table 1 below.

Table 1: Distribution of Spills in the Plant

Shipping	9%
Recovery	8%
Warehouse	11%
Manufacturing	30%
Process Piping	14%
Tank Storage	17%
Labs	10%
Off site transport	4%

The data clearly shows that the majority of spills occurs in the manufacturing process area.

1.3 Effects of Toxic and Hazardous Substance Spills

1.3.1 Introduction

Accidental spills of hazardous substances can result from a variety of causes including highway, rail, water and industrial plant upsets, the failure of retaining dikes, storm damage and malicious acts. The cost of returning the environment to an acceptable state after a spill can involve the expenditure of millions of dollars, yet undesirable effects may still remain for many months or years after the toxicants have been removed. The following outlines some of the impacts on the environment, wastewater treatment plants and the economy that can result from the spillage of hazardous substances.

1.3.2 Environmental Effects

The incorrect disposal or spillage of hazardous substances has the potential to impair the quality of either the hydrosphere, geosphere, atmosphere and biosphere, or all four at once simultaneously. This is illustrated in figure 1 below, which shows how pollutant species such as in a toxic chemical spill may be interchanged among the atmosphere, hydrosphere, geosphere and biosphere.

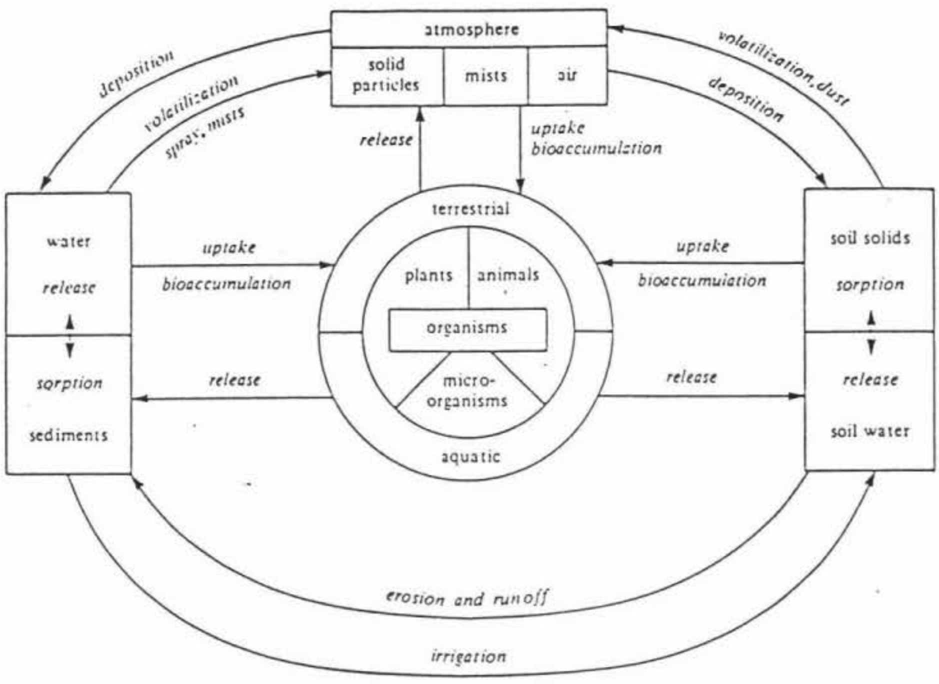


FIGURE 1. Interchange of Pollutant Species Among the Atmosphere, Hydrosphere, Geosphere and Biosphere

There are a number of environmental effects that can result from the spill of a toxic hazardous substance. The effects will depend on the volume and type of substance that is spilled. Usually the most environmental damage occurs immediately when a spill of hazardous materials reaches the aquatic environment. When a spill reaches the aquatic environment it can have the following effects:

1) destruction of all or part of the indigenous biota.

2) impairs the ecosystems function in a variety of ways such as destruction of habitat, elimination of organisms, and chemical and physical effects.

3) places the ecosystem in disequilibrium and this may be extended if persistent residual toxicants remain.

For these reasons it is desirable to prevent a spill from entering the aquatic environment.

Toxic substances may produce damaging effects in animals by absorption through external membranes, the ingestion of contaminated solids and fluids, or the inhalation of contaminated air. The result may be death or injuries, such as burns, impairment of neurological functions, or reductions in physiological processes. Spills of highly toxic hazardous substances produce shocks that quickly alter natural processes in the environment, consequently meeting with potential disastrous outcomes.

1.3.3 Effect of Spill Entry into Municipal Wastewater Treatment Plants

Ideally, untreated hazardous waste materials should not be allowed to enter wastewater treatment systems. However, the fact remains that hazardous materials do enter municipal wastewater treatment systems through illegal discharges or accidental spills. Federal studies in the U.S.A. have shown that most hazardous wastes currently enter municipal wastewater treatment systems via industrial process-water streams (Bennett et al., 1982, pp4.3). Another common way in which hazardous materials enter wastewater treatment systems is from the flushing of spilled materials by emergency response units such as fire departments. This practice of flushing spills down sewer drains being a very common practice by the N.Z. Fire Service.

There are a number of adverse effects that result from hazardous substances entering municipal wastewater treatment plants.
These effects are as follows:

1) Flammable or toxic materials pose an explosive, as well as, health hazard within the treatment plant.

2) Materials can be corrosive and, therefore, damaging to the plant.

3) Biological processes, which are common in most treatment plants, can be upset due to shock loadings. Resulting in the reduction of removal efficiency, for example 200 mg/L of phenol is inhibitory to activated sludge.

4) Hazardous materials could pass straight through the plant, therefore violating water quality standards.

5) Hazardous substances can accumulate in the biomass and suspended solids, therefore creating a problem in the disposal of contaminated sludge.

As spills of hazardous substances are not planned, there is little forewarning of the impending problems that the wastewater treatment plant may face and, therefore, is greatly disadvantaged in being able to respond effectively.

1.3.4 Economic Effects

There are several major parameters that have been identified and quantified which affect the economic impact of hazardous substance spills. These factors have been identified as follows (Bennett et al., 1982, pp 4.27 - 4.28):

1) Number of discharges occuring annually.
2) Volume of the discharge.
3) Value of the product lost, less the value of the product recovered suitable for further commercial use.
4) Cost of retrieval and cleanup efforts, including cost of the mitigation chemicals used.
5) Loss due to the disruption of the production process.
6) Cost of equipment and property damaged and destroyed.
7) Cost of damage to non-plant property.

8) Cost of damage to the environment, including loss of commercial fishing and shell harvesting revenues.
9) Cost of compensation and/or injury to employees, including cost of lost time due to injury.
10) Cost of lost water usage, including industrial, municipal, agricultural, recreational, household, and drinking-water supply and aesthetic water uses.

The above factors only identify to a certain extent the economic impact of hazardous substance spills.

1.4 Response Methods to Spills

1.4.1 Introduction

There is a limitless variety of possible spill situations that may be encountered. For example, a spill may occur at an industrial plant during a processing or loading operation or in the field during the transit of materials. Facilities to respond to spills in industrial plants are generally more readily available than those in the field. Even though the best current design technology for chemical handling and containment equipment is implemented and operating and maintenance personnel are trained to minimise the likelihood of spill occurrences, accidental spills do occur. In many spill events, the quantity and toxicity of the spilled chemicals is great enough to cause catastrophic and permanent biotic damage. For this reason it is essential that effective methodology to minimise spill damage be readily available. R.C. Scholz (1982) has identified three primary aspects of spill response:

- -control at the source
- -containment
- -recovery and/or treatment

1.4.2 Control at the Source

Control at the source is the action taken to terminate the discharge of hazardous materials and to isolate already spilled materials to the immediate vicinity of the discharge point. Control of the discharge typically includes such actions as:

- -righting an overturned and spilling container.
- -pumping the contents of a leaking container into a different container.
- -plugging a leak or closing a valve.
- -changing the properties of the substance in the container. (solidification, gelling, gasification or burning)
- -chemical conversion of the substance in the damaged container.
- -even stopping improper disposal activities.

It is very desirable to prevent the dispersion of a spill over and into soil and into ground water and surface water supplies. This being due to the fact that hazardous spills dispersed into soils and ground water are very expensive to treat and recover and the operation is also time consuming and often incomplete. In comparison control at the source can be effective and nearly complete, and can even lead to product recovery.

1.4.3 Containment

Containment of the spill involves limiting the dispersion of the spill to permit the recovery and treatment of the hazardous material. Containment methods may include the following: dikes, berms and dams; trenches; booms; barriers in soil; stream diversion; patching and plugging of containers or vessels; portable catch basins; over-packed drums or other forms of containerisation; and reorientation of the container. While there are many techniques for the containment of spills, only a few of these are discussed further.

1.4.3.1 Dikes, Berms and Dams

Dikes, berms and dams are typically used to contain spills on land or in water. Retention dikes and underflow dams may be used to contain floating insoluble materials; whereas dike usage is limited to either containment of an entire water body or development of a diversion pathway. Dikes, berms and dams are typically constructed from earth, sediment, gravel, coarse sand, or polyurethane.

1.4.3.2 Trenches

Trenches are often used as a first step to contain a spilled material prior to treatment. Trenches are effective and relatively inexpensive containment measures which can be used for land spills involving liquids and water spills involving insoluble sinkers.

1.4.3.3 Pumping

The pumping of spilled materials into a holding tank or any other container has shown to be most applicable to small spills of hazardous liquid materials on land (Unterberg et al., 1988, p162). The spilled material is typically diverted into a trench or some other type of excavation from which it is pumped into a container for further processing or disposal. Pumping is also very useful for the removal of accumulated pools of flammable material, therefore reducing the potential of a large fire, if ignited. Pumping has been used as a removal technique for water spills of both solid and liquid hazardous materials.

1.4.3.4 Dispersion/Dilution

Spills on land are generally diluted by means of water sprayed onto the spill. Diluting of land spills is primarily used to reduce the vapour hazards associated with the spill. The area around the spills should always be diked in order to prevent run-off from entering nearby waterways, sewers and stormwater drains. Under no circumstances should a hazardous substance spill on land merely be dispersed by using water (Unterberg et al., 1988, p163).

Prior to the use of dispersion, careful examination of the specific spill situation and the potential toxic effects must be considered. Dispersion should not be considered as a first choice response method, especially in the case of spills into water. If other methods of containment and treatment are available, they should be used.

1.4.4 Recovery and/or Treatment

The efficiency and cost-effectiveness of recovery and treatment of spills primarily depends on the ability to contain the spill successfully. For effective treatments, it is necessary to contain the spill in as highly a concentrated form as possible. The treatment of spills can be broadly classified into two types:

1) those spills that require the removal of contaminants to a treatment system located at the spill where contaminants are detoxicified or reduced to safe levels.

2) those spills in which treatment is applied to the contaminants directly (in situ treatment). In situ treatment is often applied where containment of the spill is not possible.

There are a number of treatment systems used in the cleanup of spill sites. These systems are mobile and usually consist of modular equipment that can be easily brought onto a site. The technologies used in mobile treatment systems are discussed further in section 1.5 following.

1.4.5 Prioritising Chemical Spills

To be able to respond effectively to chemical spills, the use of statistical spill data is extremely useful for setting priorities and identifying project needs for spill prevention and preparedness. In 1980 the Canadian Environmental Emergencies Branch developed a spill priority list, with the main objective to identify the minimum number of chemicals that would account for the maximum number of spills. The list would be used to act as a focus for the development of countermeasures, analytical methods and spill manuals. This priority list has been recently updated to form the 1990 spill priority list which is shown in Table 2 overleaf.

Table 2: 1990 Chemical Spill Priority List

THE TOP 50 MATERIALS

Acetic acid
Aldrin
Aminocarb
Ammonia
Ammonium hydroxide
Ammonium nitrate
Ammonium phosphates
Ammonium sulfate
Benzene
Calcium chloride
Calcium hydroxide
Calcium hypochlorite
Carbon tetrachloride
Chlorine
Copper sulfate
Ethylbenzene
Ethylene dichloride
Ethylene glycol
Ethylhexanol
Fenitrothion
Ferric chloride
Formaldehyde
Hydrochloric acid
Methyl alcohol
Nitric acid
nonylphenol
PCBs
Pentachlorophenol
Perchloroethylene
Phenol
Phosphamidon
Phosphoric acid
Phosphorus
Potassium chloride
Propylene oxide
Sodium carbonate
Sodium chlorate
Sodium chloride
Sodium cyanide
Sodium hydroxide
Styrene
Sulfur
Sulfur dioxide
Sulfuric acid
Tetraethyl lead
Toluene
Vinyl acetate
Xylene
Zinc sulfate
2,4-dichlorophenoxyacetic acid

The Chemical Spill Priority List was developed by taking all known spill priority lists, such as those published by the United States Environmental Protection Agency, The American Association of Rail Roads and The United States Coast Guard. Lists of material from the Transport of Dangerous Goods Act were also included. The list was reviewed and cut to form priority lists of the top 10, 25, 50, 150, 250 and 500 chemical spills (refer to Fingas, Stone, LeBlanc, Sergy et al., 1990). The chemicals are rated on the basis of spill number, spill volume, production volume, aquatic and mammalian toxicity. The utility of the spill priority list in terms of spill number, spill volume and chemical supply is given in figure 2.

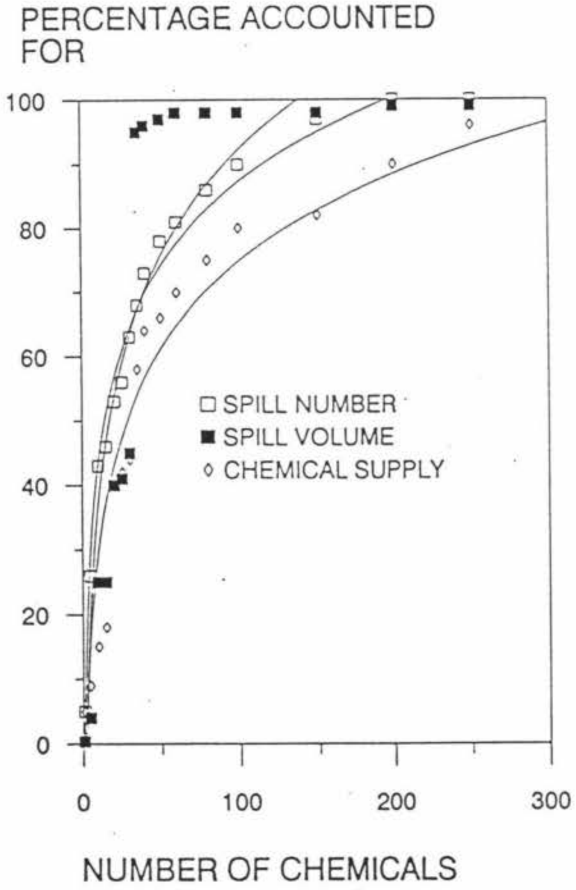


FIGURE 2. Utility of the 1990 Priority List

1.5 Mobile Treatment Technologies

Introduction

Mobile treatment technologies have been developed for emergency response and are used to contain, collect, and provide preliminary treatment of accidentally released hazardous materials and contaminated water. The Environmental Protection Agency (E.P.A.) in the United States of America has developed several types of mobile treatment systems for emergency response of which some have been used in the cleanup of Superfund sites. They usually consist of modular equipment that can be brought on site by truck or railcar. Some of these mobile treatment technologies are discussed further in this chapter.

1.5.1 Biological Treatment Technologies

There are a number of biological treatment technologies existing for the treatment of aqueous waste streams contaminated at low to moderate levels with non-halogenated organics and some halogenated organics.

The basic processes available are:

1) *Aerobic biological treatment*:
a tank based process using oxygen metabolising organisms and careful process control for low-strength aqueous waste streams contaminated with low levels of non-halogenated organics and/or certain halogenated organics.

2) *Anaerobic biological treatment*:
a tank based process using micro-organisms capable of chemical biodegradation in the absence of oxygen. Careful process control and extended retention time is required.

3) I*n situ biodegradation*:
use of existing indigenous aerobic bacteria, or, introduced cultured strains in soil. Activity is often accelerated with the addition of nutrients. Biodegradation of organics in soil or ground water may require 6 to 18 months.

Rationale for Biological Treatment:

1) Bacteria are natural components of ecological systems. Their use as a countermeasure ensures that foreign material is not introduced.

2) Bacteria will metabolise organic hazardous materials to the principal end products carbon dioxide and water according to the general equation:

$$C_x H_y O_z + O_2 \Longrightarrow CO_2 + H_2O$$

Biological treatment measures may be employed in one of two ways:

1) in situ to a spill of hazardous material, this is, in the receiving water itself,

2) by pumping the toxic spill to a mobile biological treatment system brought to the spill site.

For either treatment system the amount and nature of the toxic chemical spill needs to be determined so that the appropriate bacteria may be used and the proper amount of bacterial culture applied. Once the nature and amount of hazardous material spilled have been determined, and once containment has been achieved or at least ambient concentration determined, the bacterial treatment measures may be deployed.

1.5.2 Chemical Treatment Technologies

1.5.2.1 Neutralisation

Neutralisation is the interaction of an acid or a base to adjust the pH of a mixture or solution to between 5 and 9. It can be used as either a final waste treatment process, or as a pretreatment process to prepare a waste stream for further treatment. Acid spills are typically neutralised by using lime, limestone or sodium hydroxide, and alkaline spills by either HCL and in some cases H_2SO_4. The quantity and concentration of the neutralising reagent used depends on the influent and the desired pH of the effluent. Equipment used in a mobile neutralisation treatment system typically consists of a chemical feed system and a rapid mixing process, followed by another physical/chemical process for by-product removal as required.

Waste Streams Treated :

Neutralisation is typically used on liquids, but can also be used to treat the following wastes:

-Organic and inorganic waste streams
-Spent acid and alkali wastes
-Sludges, slurries and gases

Disadvantages:

-spent acid and alkali wastes with pH between 4.0 and 9.0 may not be treated effectively by neutralisation.

-solids and sludges may require large dosages of chemicals, due to the difficulty of achieving complete mixing and the potentially high buffer capacity of solid phases.

-toxic gases, such as ammonia and hydrogen cyanide may be released if wastes are not mixed slowly and are not properly prepared.

-heavy metals may be precipitated out from the solution and result in significant quantities of sludge.

-chemical complexes may not be effectively removed during further processing.

-additional processing of sludges may be required due to regulatory requirements for disposal of sludges.

1.5.2.2 Precipitation

Precipitation is the physical/chemical process in which dissolved chemical species in solution, for example, metals, are transformed into solid phases for removal. The chemical equilibrium relationships between the soluble substances are generally altered by the addition of chemicals, such as lime and sodium sulphate. Additional chemicals are sometimes required to adjust the pH of the mixture, since the solubility of the metal hydroxide and sulphides is very dependent on pH. The equipment required for precipitation include:

-Reaction tank with rapid mixing
-Chemical storage tanks
-Chemical feed pumps
-pH controls
-Clarifiers, filters and centrifuges may be required for the
dewatering of sludges

Waste Streams Treated:

Precipitation is well suited for detoxifying aqueous solutions containing heavy metals and suspended solids. Waste waters contaminated with heavy metals are typically treated using precipitation. The heavy metals include:

-Arsenic
-Cadmium
-Chromium
-Copper
-Iron
-Lead
-Manganese
-Mercury
-Nickel
-Zinc

Disadvantages:

-organic compounds can interfere with precipitation by forming organometallic complexes.

-each metal salt has a different optimum pH for maximum removal and precipitation.

1.5.2.3 Dechlorination

Dechlorination is a process whereby chlorine is chemically removed from chlorinated organic compounds, such as P.C.B.s and dioxins. The treatment system uses a sodium-based reagent composed of an alkali metal and polyethylene glycol. Dechlorination is achieved by nucleophillic displacement of chlorine atoms by polyethylene glycol, to form an alkali metal chloride (typically KCl or NaCl) and a substituted organic polymer. By-products of the dechlorination process include chloride salts, polymers, and sometimes even heavy metals.

The equipment required for a dechlorination system is as follows:

- -Reaction vessel
- -Mixing chambers
- -Reagent storage tanks
- -Chemical feed pumps
- -Dual filter beds
- -Vacuum degasser

Waste Streams Treated:

Portable dechlorination treatment systems have been limited to the treatment of P.C.B. contaminated transformer fluids (organic fluids). Chlorinated acids and thiols have also been chlorinated by this process.

Disadvantages:

-the process should take place in a nitrogen atmosphere due to the reagents being air and water sensitive.

-moisture content adversely affects the rates of reaction and dewatering should be a pre-treatment step.

-contaminant concentration is a limiting factor. For example, P.C.B. concentrations exceeding 5,000 ppm cannot be treated cost effectively, due to excessive sodium requirements.

1.5.3 Physical Treatment Technologies

Physical treatment processes separate the waste stream by either applying physical forces or changing the physical form of the waste. In either case the chemical structure of the substance in the waste stream remains the same. Physical processes are usually simple, relatively inexpensive and can be applied to a wide range of wastes.

1.5.3.1 Air Stripping

Air stripping is a process, by which dissolved molecules are transferred from a liquid into a flowing gas. The driving force for mass transfer is provided by the concentration gradient between the liquid and gas phases, with solute molecules moving from the liquid to the gas until equilibrium is reached. When the process is applied to hazardous waste treatment it is primarily used to remove relatively volatile dissolved organic contaminants, such as toluene and trichloroethylene from water or aqueous waste. Air stripping has been successfully used in the cleanup of ground waters contaminated with low levels of volatile solvents (Byers & Morton, 1985). Air stripping has also been used for the removal of volatiles from industrial aqueous wastes containing traces of dissolved solvents.

Air stripping is most efficiently carried out in a packed tower with a countercurrent flow of air and water. Contaminated water is pumped to the top of the tower and distributed uniformly across the packing. It flows downward in a film layer along the packaging surfaces. Air is blown into the base of the tower and flows upwards, contacting the water. Packed-tower operation provides a high level of turbulence and a very large surface area for mass transfer. Volatile organics are transferred from the water to the air and carried out the top of the tower. Packed towers in portable systems are typically constructed out of fibre reinforced plastic making them lightweight and structurally sound.

Disadvantages:

-limited only to dilute liquid aqueous wastes with volatile organic concentrations less than approximately 100 mg/ L (Freeman et al., 1989).
-suspended solids in the waste stream should be removed prior to air stripping.

-the process effectively converts a water pollution problem to an air pollution problem, as the gas leaving the top of the tower contains all toxic volatile organic compounds removed from the waste water stream. Therefore, air pollution controls are sometimes required.

1.5.3.2 Ion Exchange

The process of Ion Exchange involves the removal of anions and cations dissolved in a dilute aqueous waste. Ions are held by electrostatic forces to functional groups on the surface of a solid and are exchanged for ions of a different species in solution. The exchange takes place on a synthetic resin. Various types of resins are available, including weakly and strongly acidic cationic exchangers and weakly and strongly basic anion exchangers.

A significant feature of ion exchange is that it has the ability to separate, or purify, as well as concentrate pollutants. Some exchangers are selective for certain metals and can remove low concentrations of toxic metals, such as sodium or calcium. Ion exchange can also be used in some applications to purify a spent chemical concentrate by removal of low-level contamination.

To date the greatest use of ion exchange has been in the treatment of inorganic wastes. This has been mainly due to the fact that standard exchangers exhibit unfavourable kinetics of sorption for organic species from liquids non-polar in character and because the molecular weight of many organics is too high to permit ion exchange at practical rates in polar solutions. Ion exchange is an external treatment process in which the spilled material is pumped through a column containing an appropriate resin.

Disadvantages:

-chemical wastes are produced if excess regenerant is required.

-there are limitations on the concentration of what can be treated and produced.

-down-time is required for regeneration.

-resins cannot yet be made which are specific to a particular substance.

-ion exchange resins are prone to fouling by some organic substances.

1.5.3.3 Membrane Separation

There are a number of membrane separation technologies available. These include reverse osmosis, hyperfiltration, ultrafiltration and electrodialysis. Membrane technologies separate solutes or contaminants from liquids through the use of semi-permeable membranes. These semi-permeable membranes function by selectively rejecting contaminants based on pore size, ion valence or co-precipitation. To date reverse osmosis is the only membrane technology that has been used as a mobile system.

The reverse osmosis system allows a solvent such as water to be removed from a solution containing solutes by the application of a pressure driven membrane process. During the process solvent molecules (water) are forced through the microscopic pores of the semi-permeable membrane by achieving sufficient hydrostatic pressure to overcome the concentrate osmotic pressure. As the solvent flows through the membrane, the larger organic and inorganic compounds are rejected. The effectiveness of a reverse osmosis system depends on the following:

-temperature of the solution
-pressure of the system
-pH of the solution
-chemical and ohysical structure of the membrane

Waste Streams Treated:

Reverse osmosis has been used in effectively treating the following:

-P.C.B.s and chlorinated organics in groundwater
-Waters with high BOD levels present
-Insecticides/herbicides in groundwater
-Organic and inorganic leachate

Disadvantages:

-suspended solids and oils must be removed to avoid fouling of the membrane.

-process residuals which include solutes that remain in the effluent in the range of 10 - 100 ug/L, and concentrate solution (10-20 % of feed volume).

1.5.4 Activated Carbon Adsorption

Activated carbon adsorption is one of the most frequently applied technologies for the removal of trace organic compounds from an aqueous solution. In the adsorption process, molecules attach themselves to the solid surface through attractive forces between the adsorbent and the molecules in solution.

Activated carbon will adsorb most organic compounds to some degree. Factors that affect the adsorption process include:

-Carbon pore structure
-Carbon contact time
-Temperature
-pH

Waste Streams Treated:

Carbon adsorption can be applied to a wide range of waste streams containing organic compounds. Classes of organic compounds amenable to adsorption on activated carbon are given in Table 3 below.

Table 3. Classes of Organic Compounds Amenable to Adsorption on Activated Carbon

Aromatic solvents	Benzene, Toluene, xylene
Polynuclear aromatics	Naphthalene, Buphenyls
Chlorinated aromatics	Chlorobenzene, PCBs, Aldrin, Endrin, toxaphene, DDT
Phenolics	Phenol, cresol, resorcinol
High-molecular weight aliphatic amines and aromatic amines	Aniline, toluene diamine
Surfactants	Alkyl benze sulfonates
Soluble organic dyes	Methylene blue, textile dyes
Fuels	Gasoline, kerosene, oil
Chlorinated solvents	Carbon tetrachloride, perchloroethylene
Aliphatic and aromatic acids	Tar acids, benzoic acids

(O'Brien et al., 1983)

Disadvantages:

Waste streams with low molecular weights, high polarities and high solubility do not readily adsorb on to activated carbon. Activated carbon adsorption is also not recommended for waste streams containing a high solids content (greater than 500mg/L), unassociated metals and high humidity gas streams.

2 ADSORPTION TECHNOLOGY

Adsorption is the separation of a substance from one phase accompanied by its accumulation or concentration at the surface of another. The adsorbing phase is the *adsorbent* while the material concentrated or adsorbed at the surface of the adsorbing phase is the *adsorbate*. Adsorption is, therefore, different to absorption, a process in which material transferred from one phase to another interpenetrates the second phase to form a solution.

Adsorption involves the separation of substances from a variety of gases and liquids at a variety of interfaces and surfaces. Adsorption from liquids at solid surfaces is the most common category and uses the most comprehensive range of factors.

2.1 Adsorption Principles

2.1.1 Types of Adsorption

Adsorption results from a variety of different types of attractive forces between solute molecules, solvent molecules and the molecules of the sorbent. These intermolecular forces act on the molecules at the surface of the adsorbent as opposed to the bulk phase molecules in absorption. There are three loosely defined categories of adsorption. *Physical*, *chemical* and *electrostatic* are traditionally distinguished according to the class of attractive force which predominates (Weber et al., 1990). *Electrostatic* or *exchange adsorption* involves electrostatic attachment of ionic species to sites of opposite charge at the surface of an adsorbent, with subsequent displacement of these species by other ionic adsorbates of greater electrostatic affinity. *Physical adsorption* results from the action of Van der Waals forces. *Chemical adsorption* involves the chemical reaction between adsorbate and adsorbent resulting in change in chemical form of the adsorbate.

2.1.2 Adsorbent Properties

As adsorption is a surface phenomenon, practical commercial adsorbents are therefore characterised by large surface areas. The majority of which is compromised of internal surfaces bounding the extensive pores and capillaries of highly porous solids. Furthermore, practical commercial adsorbents are required to have adequate abrasion resistance and be easily transportable. Abrasion resistance is required to assure that the granules of the adsorbent are not reduced in size during handling or crushed under their own weight during columnar operation; abrasion resistance being especially important in upflow columns (Valencia G. & Gloyna E.F., 1972). Ease of transportation is required for an effective changing of columns and tanks, using slurries. Activated carbon has found to meet the above requirements and is one of the most widely used porous adsorbents because of its capability for efficiently adsorbing a broad range of different types of adsorbates.

2.1.3 Adsorption Rates

There are 3 consecutive mass transport steps associated with the adsorption of solutes from solution by porous adsorbents:

1) Bulk transport of solute in the solution phase (rapid).

2) Film transport, diffusion of the solute through a hypothetical "film" or hydrodynamic boundary layer.

3) Intraparticle transport, solute diffuses within the pore volume of the adsorbent.

Film and intraparticle transport being the major factors controlling rates of adsorption from solution by porous adsorbents, i.e rate of adsorption is governed by the transport (diffusion) of the solute molecules within the pores of the adsorbent particle. Diffusion is thus affected by the following:

-size of the solute molecule
-size, shape and volume of adsorbent pores
-radius of adsorbent particle

The size range of the particles should be as narrow as possible; the largest particles control the rate and give the lowest adsorption performance, while the smallest particles control the pressure drop.

2.1.4 Adsorption Equilibria

In order to be able to use adsorption as a waste-management process, it is necessary to understand how the equilibrium state varies as a function of the system conditions. Adsorption of the solute onto the adsorbate continues until the concentration of adsorbate or solute remaining in solution is in dynamic equilibrium with the concentration of solute adsorbed onto the surface of the adsorbent. When this equilibrium position is reached, no further net adsorption takes place and there is a well defined distribution of the solute between the aqueous and solid phases. The distribution is defined as the amount of substance adsorbed per unit weight of adsorbent, qe, as a function of the residual equilbrium concentration, Ce, of substance remaining in the solution phase. This expression is termed an *adsorption isotherm* and defines the functional equilibrium distribution of adsorption with concentration of adsorbate in solution at constant temperature. This can be illustrated graphically as shown in figure 3.

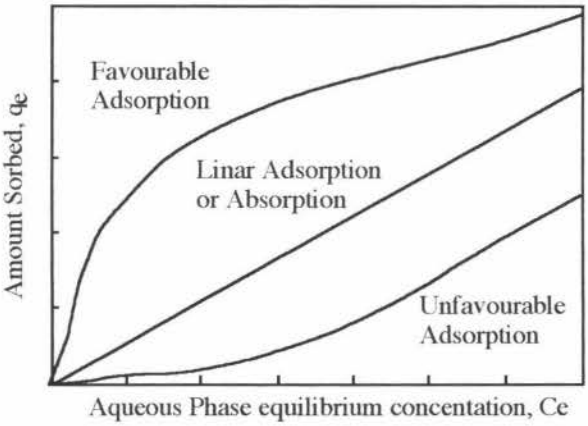


FIGURE 3. Illustration of General Types of Sorption Isotherms
(Weber, 1991)

Isotherms determined experimentally are used to describe adsorption capacity so that the feasibility of the adsorption process for a given application can be evaluated. Moreover, the isotherm plays a crucial functional role in predictive modelling procedures for analysis and design of adsorption systems (Weber & Crittenden, 1975). Emperical observation of the adsorption process has led to the development of generalised expressions which have been used to describe adsorption. In the case of wastewater adsorption, equilibria is best described by an emperical relationship developed by Freundlich (Valencia, 1972). The Freundlich expression is typically quoted as:

$$q = KC^{1/n} \qquad \text{(Equation 1)}$$

where

q = amount of solute adsorbed per unit weight of carbon (mg/g or moles/g).

C = concentration of solute in solution at equilibrium (mg/L or moles/L).

K = constant related to the adsorptive capacity of the carbon.

n = constant related to the energy of adsorption.

Equation 1 may be represented in a linear form as:

$$\log q = \log K + 1/n \log C \qquad \text{(Equation 2)}$$

A plot of log q versus log C should give a straight line of slope 1/n, and intercept at C = 1 equal to log K if the data fits this isotherm. A typical plot is shown in figure 4 below.

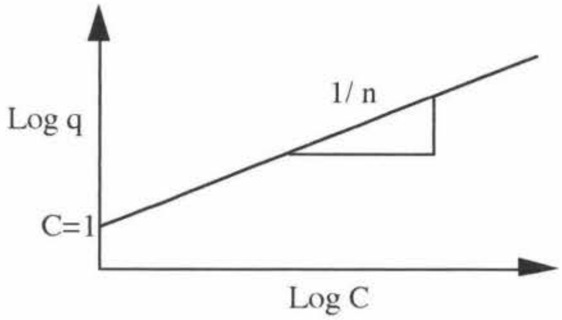


FIGURE 4. Log q versus Log C

The Freundlich expression is typically used to express a large number of experimental results in the field of Van der Waals adsorption in the middle concentration range (Noll et al., 1992).

2.1.5 Activated Carbon Adsorption

Activated carbon is any amorphous form of carbon that has been treated to give high adsorption capacities. It is made by heating organic matter such as wood, coal, pulp mill and petroleum based residues and char to leave a carbon residue which is then activated by partial oxidation with carbon dioxide, steam, or oxygen in air. Activation introduces pores in the carbon, increases its surface area (up to as much as $2000 m^2/g$), and introduces chemical groups onto the surface. The structure of activated carbon consists of elementary microcrystallites of graphites, these microcrystallites are stacked together in random orientation and it is the spaces between the crystals which form the micropores. The surface of activated carbon is essentially non-polar although a slight polarity may arise from surface oxidation. As a result, carbon adsorbents tend to be hydrophobic and organophillic. They have an affinity for sorbed materials, particularly non-polar organic compounds. Activated carbon has a high adsorption capacity due to the large available surface area (500 -

$1500 m^2/g$) resulting from a large number of pores. Activated carbon comes in the form of granular activated carbon (G.A.C.) and powdered activated carbon (P.A.C.).

Generally carbon adsorption is applicable to single-phase fluid waste streams, for example liquid solutions or gas mixtures. It removes organic and some inorganic chemicals from water. It has also be proven to be good for removing mixed organics from water, select inorganics from water, or to remove select organics/inorganics from aqueous solution. Solutes that have a high molecular weight, low water solubility, low polarity and a low degree of ionization have high attractiveness (high affinity for carbon), therefore, are more readily removed from the waste stream. The major ones of these are summarised in table 4.

The adsorption of inorganic waste streams by G.A.C. has proven to be relatively poor to date. It has, however, been shown that G.A.C. is capable of removing cyanide and chromium from electroplating wastes, as well as other heavy metal ions, such as mercury.

Table 4. Solutes Readily Removed from Waste Streams by Carbon Adsorption

- **Hydrocarbons**

  Aromatic hydrocarbons: Monocyclic aromatic hydrocarbons commonly used as solvents and present in fuels (benzene, tolune, xylene), napthalene (U165), biphenyl, polycylic aromatic hydrocarbons

  Aliphatic hydrocarbons: Constituents of gasoline, kerosine, jet fuel; lubricating oils; solvents such as cyclohexane (U056).

- **Chlorinated hydrocarbons**

  Trichloroethylene (U228), 1,1,1-trichloroethane, chlorobenzene (U037), polychlorinated biphenyls, chlorinated hydrocarbon insecticides, such as toxaphene and 2,4-D

- **Phenolic compounds**

  Phenol (U188), cresols (U052), 1-naphthol, pentachlorophenol (F027)

- **Organonitrogen compounds**

  Amines: Aniline (U012), diaminotolune (U221)

- **Dyes**

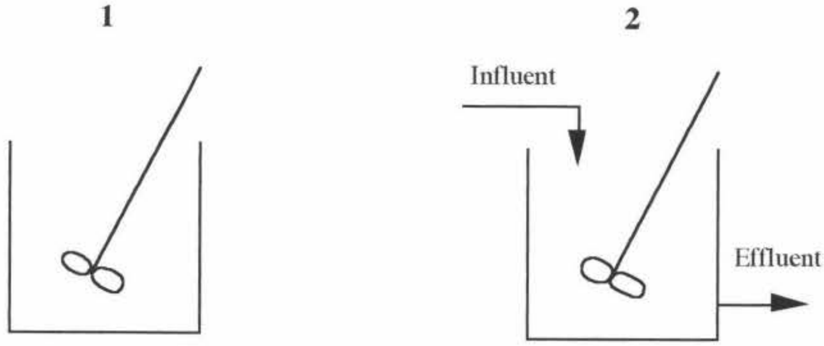
- **Surfactants**

2.2 Reactor Adsorption Systems

The way in which the adsorbate is contacted with the adsorbent is of extreme importance when it comes to the design of reactor adsorption systems. There are several different reactor configurations that exist. The most common of these reactor systems being :

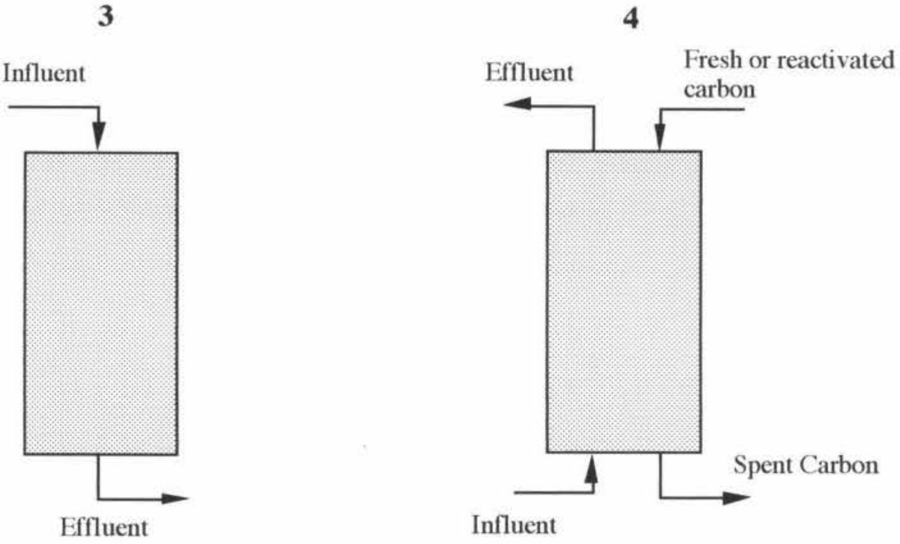
1) Mixed Batch reactor
2) Mixed Flow reactor
3) Fixed Bed reactor
4) Pulsed or Moving Bed reactor

These reactor systems are shown graphically in figure 5.



Completley Mixed Batch Reactor (CMBR)

Completely Mixed Flow Reactor (CMFR)



Fixed Bed Reactor

Pulsed or moving Bed

FIGURE 5. Reactor Adsorption Systems

The Mixed Batch reactor system is seldom used because of its low adsorbate removal efficiency and the fact that it requires the use of pure carbon (Noll et al, 1992). The Mixed Flow reactor also suffers from the problem that the carbon capacity is poorly utilised and the fact that the reaction rate is controlled by the steady state solution concentration. The reactor must, therefore, be operated at a point far from equilibrium by adding more P.A.C. than is required (at equilibrium), which results in an additional inefficiency in adsorption capacity utilisation (Noll et al., 1992). The Fixed Bed reactor system, however, does not suffer from the same problems that the Mixed Batch and Mixed Flow reactors suffer from. Moreover, the Fixed Bed reactor is the most efficient arrangement for conducting adsorption operations. The Fixed Bed Reactor system is detailed further in section 2.2.1.

2.2.1 Fixed Bed Reactor Adsorber Systems

The Fixed Bed reactor is a columnar continuous plug flow configuration. Such a reactor consists of a packed bed of adsorbent through which the influent stream under treatment is passed. The polluted stream travels through the packed bed and contaminants are adsorbed on to the adsorbent and a purified effluent then exits the column.

The adsorbent at the inlet of the bed is continuously in contact with the influent stream. The concentration of the fluid in contact with a given layer of adsorbent changes very slowly under this condition, and high uptake of the adsorbate by the adsorbent is achieved. The adsorbate at the inlet of the column becomes fully loaded first followed by the downstream adsorbate.

Part of the bed displays a gradient in solid concentration from zero to equilibrium and is called the Mass Transfer Zone (M.T.Z.) as shown in figure 6. This zone being where adsorption actually takes place. When a solution is passed through a stationary adsorber, non-steady state conditions prevail, i.e. the adsorbent continues to adsorb steadily increasing amounts of adsorbate over the entire period of useful operation. The M.T.Z. travels downstream due to increased saturation of the bed and, therefore, eventually exits the bed. The adsorption pattern for a non-steady state adsorber is called the 'breakthrough curve'. The breakpoint on this curve is the point at which the concentration of the effluent reaches a level which has been set by effluent regulations or the designer of the system. When the effluent concentration reaches its maximum, which is theoretically equal to the influent concentration, the bed is considered to be exhausted and will require replacing or regenerating. For adsorption of a single solute in a fixed bed, design focuses upon the breakthrough curve and the tolerable quantity of impurity that can be allowed to emerge before the "run" or "cycle" is terminated.

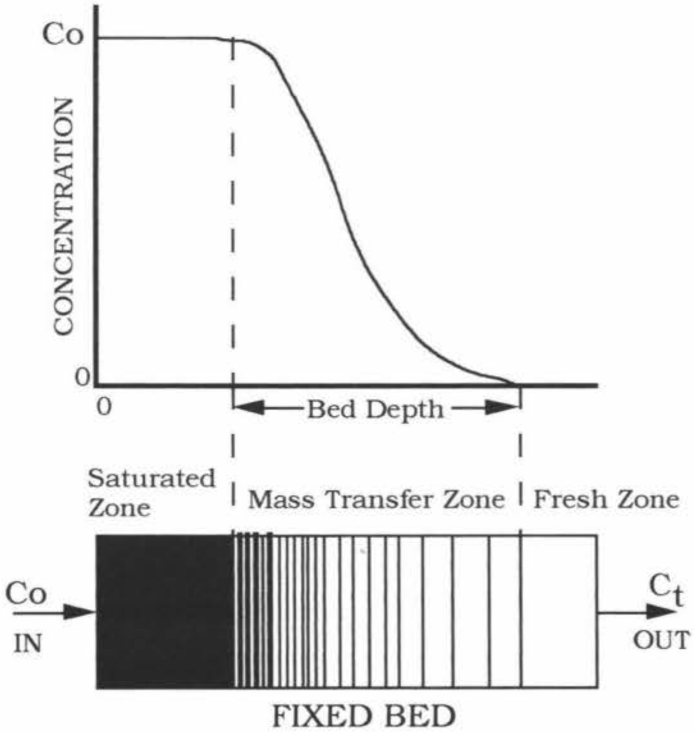


Figure 6. Concentration Profile along Column

(Noll et al., 1992)

2.3. Flow Configurations

Fixed bed adsorbers can be designed to operate in one of two flow configurations: downflow or upflow.

1) Downflow

The downflow configuration is used where the adsorbent is to perform the dual roles of adsorption and filtration. Although this results in a low capital cost because there is no need for pre-treatment filters, the bed will require more efficient and frequent backwashing due to fouling of the bed from suspended solids. Backwashing requires at least a 50% expansion of the bed in order to remove the solids. After backwashing, the adsorbent bed is stratified with the larger particles on the bottom and the smaller particles on the top. It is known that rate of adsorption increases with increasing concentration and is also inversely proportional to the square of the radius of the adsorbent particle. Therefore, the top of the stratified bed is more efficient than the bottom of the bed. A combination of low concentration and less efficient adsorbent size at the bottom of the bed results in higher effluent and less efficient treatment. However, the downflow configuration is often chosen because it is easier to design than the upflow configuration which requires careful hydraulic design.

2) Upflow

The upflow configuration while being more difficult to design in terms of hydraulics has a number of advantages. These being a minimum of pressure drop, channeling and fouling of the adsorbent. Upflow designs also allow for smaller particle sizes of adsorbent to be used which increases adsorption rates and therefore, the adsorber size can be decreased.

2.3.1 Arrangement of Multiple Adsorption Columns

When the Fixed Bed reactor system involves the use of multiple adsorption columns, these columns can be arranged in either parallel or series configurations or a combination of both. The choice of which fixed bed design is the most appropriate depends on the isotherm slope 1/n, the treatment objective, and the length of the M.T.Z. (Crittenden et al., 1987). These two common column configurations are shown in figure 7 below:

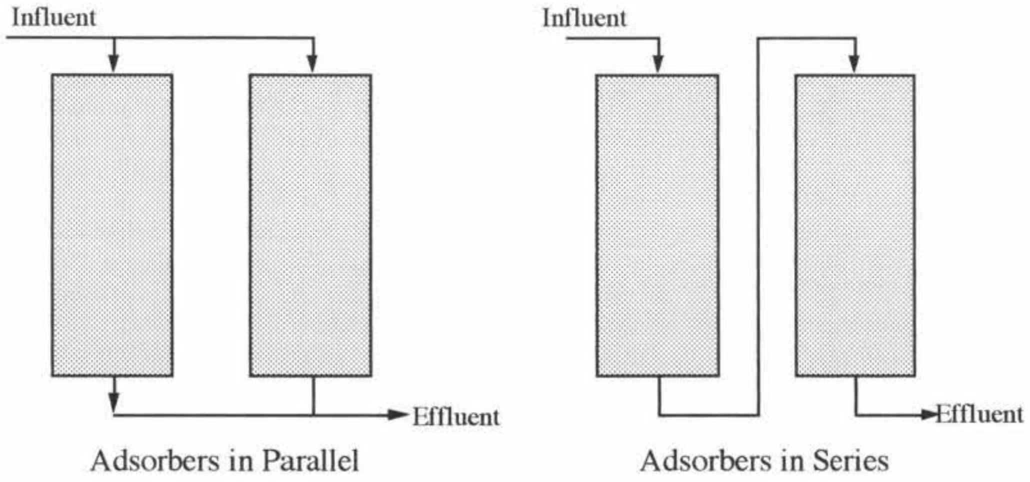


Figure 7. Column Configurations

Adsorbers in Parallel

In this column configuration the effluent from several adsorbers is blended so that a given adsorber may remain in service longer. Consequently, more of the G.A.C. capacity can be utilised.

Adsorbers in Parallel:

- For high-volume applications
- Handles higher than average suspended solids if downward flow approx 60-70ppm
- Relatively low capital cost
- Effluents from several columns blended, therefore less suitable where effluent limitations are low.

Adsorbers in Series:

Downflow

- Large volume systems
- Countercurrent carbon use
- Maximum linear velocity

Upflow

- can handle high suspended solids
- high flows in bed
- countercurrent carbon use

2.4 Design Considerations for Packed Columns

The most important design consideration is choosing the proper empty bed contact time (E.B.C.T.) and the process flow configuration (adsorbers in series or parallel), so that the G.A.C. capacity is fully utilised (Crittenden et al., 1987). There are four choices in fixed bed designs:

1) Pulsed bed
2) Beds in parallel
3) Beds in series
4) Combination of beds in series and in parallel

The choice of which fixed bed design is most appropriate depends on the isotherm slope 1/n, the treatment objective, and the length of the M.T.Z. (Crittenden et al., 1987). If $1/n < 1.0$ the M.T.Z. will remain constant in shape for a given concentration once it has been established. If the M.T.Z. is short enough to be contained or the treatment objective is stringent enough, e.g. $C_{to}/C_o < 0.05$ then a beds in series configuration is the preferred option. A beds in parallel configuration is more suited to remove adsorbates that have a treatment objective, that is not too overly restrictive, for example. $C_{to}/C_o > 0.3$ or when the M.T.Z. cannot be contained in the bed.

3. CONCEPTUAL DESIGN

3.1 Definition

It is generally accepted that the term "Conceptual Design" refers to a design that lies between a process concept and a final detailed engineering design consisting of drawings and specifications. For the purposes of the design of the prototype portable adsorption system the Conceptual Design will consist of the following elements:

1) Design Brief which defines the application, constraints and performance objectives of the system.

2) Definition of the process configuration.

3) Materials Selection.

3.2 Design Brief

The design brief given as part of this thesis is to design and develop a portable adsorption unit for the removal of accidental spills of toxic chemicals in the agricultural and manufacturing industries. The unit should be able to take up the spill or influent stream and produce a clean effluent that is safe for discharge into the local sewer/stormwater drain or even river. The desired result is that the spill can be treated on site to produce a clean dischargeable effluent.

3.2.1 Definition of Basic System Requirements

1) *Portability*: The unit is required be easily transportable between spill sites. Therefore, it must not be of a size that is unmanageable by only one or two operators.

2) *Capacity*: The unit should be able to process spills of up too 200 litres and of varying concentrations at any one time, to the desired treatment objective. It should also be capable of remaining in service for a number of spill attendances without the need to replace the G.A.C..

3) *Adsorbent*: As New Zealand is an agricultural-based economy, most of the toxic chemicals used and manufactured in this country can be readily adsorbed onto most commercially available adsorbents, such as activated carbon. Previous work carried out by Bhaskar G.V on two representative chemicals Phenol and 2,4 dichloroaceticacid (2,4-D) showed Calgon F400 Activated Carbon as being the most suitable adsorbent. The cost and ready availability of Granular Activated Carbon also support this choice.

4) *Spill Removal*: The adsorption unit must provide a means by which the spill can be removed from the spill site as quickly as possible.

3.3 Process Configuration

Process configuration for carbon adsorption systems is very much dependent upon the final application of the system. In the previous sections 3.2 and 3.2.1 the final application and system constraints were identified. From these constraints the process configuration is to be decided upon. For the purposes of this design, process configuration will define the following:

1) Reactor Adsorption System
2) Contacting System
3) Flow Configuration
4) Fluid Handling and Control

3.3.1 Choice of Reactor Adsorption System

There are several different ways in which the adsorbate can be contacted with the adsorbent. Section 2.2 of Chapter 2 identifies the four most common methods of contact . Of these four methods the Fixed Bed Reactor is considered the most efficient arrangement for conducting adsorption operations. As an important requirement of the portable adsorption unit is the ability to process a spill as quickly as possible and with the most effective use of carbon, the Fixed Bed Reactor adsorption system was the one chosen for this prototype.

3.3.2 Choice of Column Arrangement *(process flow configuration)*

As the unit is required to handle spills/influent of variable type, size and concentration a single fixed bed reactor would not be able cope with such variable conditions efficiently. Therefore, in order for the unit to be able to cope with such variations in spill/influent characteristics multiple adsorption columns will be required. When designing an adsorption system with multiple columns, the columns can be arranged in either parallel or series configuration or a combination of both. The relative merits and design considerations for each configuration have been discussed in section 2.4 of Chapter 2.

As the spill/influent is of variable characteristics, it is not possible to design the unit based on a single isotherm, treatment objective and the resulting length of the Mass Transfer Zone, as these too are dependent upon the spill/influent characteristics.

In order to account for this variability, the adsorption columns should be capable of operating in either parallel or series flow configurations or a combination of both.

3.3.3 Choice of Flow Configuration

Fixed Bed adsorbers can be designed to operate with the fluid flow through the column being either up or down - the downflow system having gravitational assistance, but because of this the optimum contact between the carbon and the influent is less effective. The downflow system also has a maximum linear velocity associated with it, and hence is more suitable to large volume systems. The upflow system, on the other hand, has a minimum head loss and minimum pre-treatment requirement. Also, the contact between the carbon and the influent is much better. Therefore, upflow systems remove more pollutant in a given time than the downflow system.

In order to help determine which is the best flow configuration to adopt, a series of small scale fixed bed adsorption experiments were carried out in both the upflow and downflow configurations.

3.3.3.1 Small Scale Column Experiments

A series of experiments was conducted on small fixed bed adsorption columns filled with granular activated carbon. The columns were run in both upflow and downflow configurations. Each column was loaded with approximately 20g G.A.C., and 1 litre of 200ppm 2,4-D solution was pumped through the column - the 2,4-D being adsorbed on to the carbon.

The objectives of the experiments being:

1) to gain familiarity with the concepts involved in carbon adsorption as applied to fixed bed columns.

2) to learn analysis techniques that will be required later in the performance evaluation of the full scale columns.

3) to show that upflow fluid flow through the columns was more effective at removing pollutants from the waste stream than the downflow configuration.

4) to evaluate the performance of each of the columns in terms of its ability to remove pollutant from the waste stream.

3.3.3.2 Experimental Procedure

The adsorption experiments were conducted using BDH activated carbon of 850 - 1400μm diameter, while 2,4-D with greater than 98% purity was supplied by Dowe Elanco Ltd, New Plymouth, New Zealand. The carbon was used without any further treatment. The concentration of 2,4-D was measured using a Varian series - 634 UV spectrophotometer at 284.1 nm and a 1 cm path length.

The following procedure was followed in the column experiments (A diagram of the experimental procedure is attached in appendix A1.):

1) Determination of a standard curve for 2,4-D made up using Dairy factory water for analysis on the U.V. spectrophotometer.

2) Making up of 5000ppm and 200ppm 2,4-D solutions.
    - dissolve 5g of 2,4-D in 500 ml of 0.1M KOH solution (100 ml KOH/gram 2,4-D).
    - make up to 1 litre in a volumetric flask with water (dairy factory supply).
    - using the 5000ppm 2,4-D solution make up 1 litre of 200ppm solution.
    - bring the 200ppm solution up to a pH of 6.5 using concentrated HCI.
    - determine the exact concentration of the 200ppm solution using the U.V. Spectrophotometer.

3) Columns are loaded with approximately 20g of G.A.C. (800μm - 1400μm diameter) and with 4mm diameter glass beads which provide the hydrodynamic zone.

4) Wet the carbon in the column by pumping water through the column for 1 hour.

5) Pump 1 litre of 200ppm 2,4-D solution through the column taking adsorbence measurements of the effluent approx every 30 seconds for 20 minutes. This is to be performed in both the upflow and downflow configurations (refer to diagram in appendix A1).

3.3.3.3 Results and Discussion

The U.V. spectrophotometer standard curve for 2, 4-D was constructed and is shown in appendix A2. From the experiments conducted, it was found that the upflow configuration gives the most optimum contact and lower exit concentration. The graph in figure 8 shows the relative effluent concentrations versus time for both the upflow and downflow configurations. It clearly shows that upflow is the most desirable configuration. The concentration versus time data for the upflow and downflow configurations is given in appendix A3 and A4 respectively.

The upflow configuration has a minimum of head loss and minimum pre-treatment requirements. Also, the contact between the carbon and the pollutant is better, whereas in the downflow configuration there is gravitational assistance which causes a greater maximum linear velocity which gives rise to less optimum contact between the carbon and the pollutant. The contact time (mean residence time) for the upflow configuration was calculated to be 30 seconds for a carbon bed with a height of 3 centimetres (refer to appendix A3 for calculations).

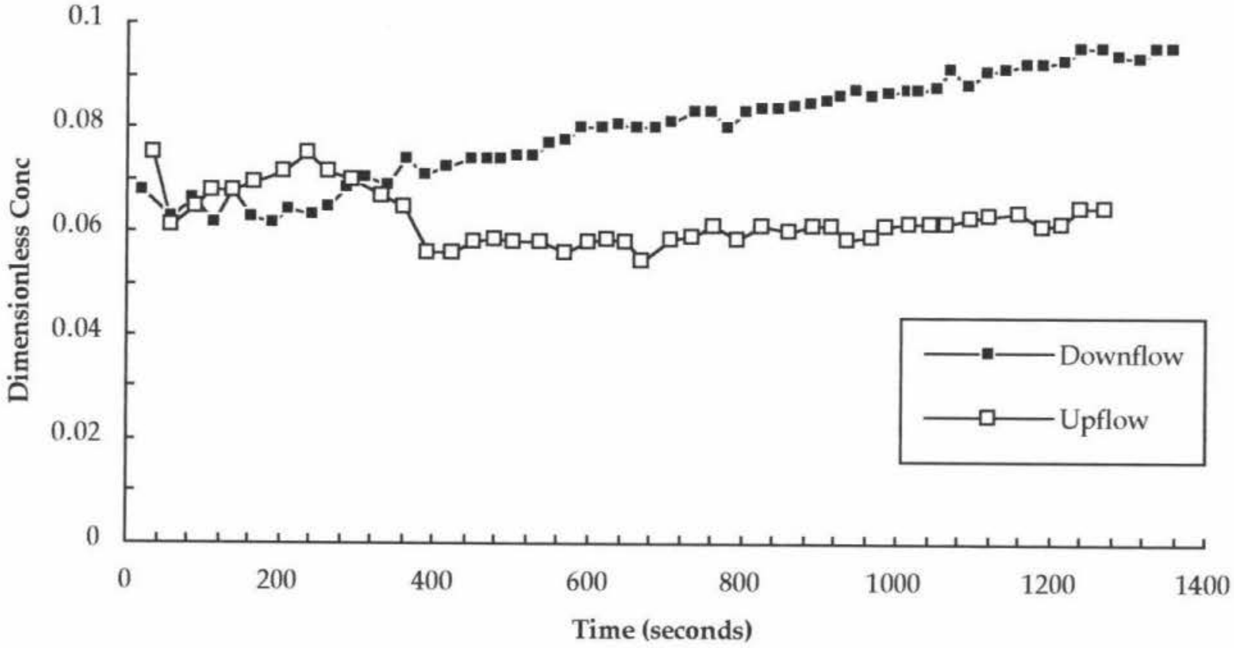


Figure 8. Dimensionless Concentration Versus Time for Upflow and Downflow Fixed Bed Adsorption

3.3.3.4 Conclusions

An upflow configuration will be adopted in the portable carbon adsorption unit, as it is able to give better contact between the pollutant and the carbon and is also more controllable than a downflow configuration.

3.4 Fluid Handling & Control

This section identifies components in the system that will be required for fluid handling and control.

3.4.1 Spill Removal Unit

A Tsurumi Wet Vacuum Cleaner, WB series is to be used in the removal of the spill from the area. The Tsurumi Wet Vacuum Cleaner has a maximum displacement capacity of 45 L/min.

3.4.2 Spill Containment Vessel

A spill containment vessel will form an integral part of the adsorption unit and is required for the following reasons:

1) *Equalisation of Flow*

> Flowrate or its reciprocal residence time has a great effect on the kinetic properties of the adsorption reaction and so any variation in flow can have a deleterious impact on system performance. In order to prevent any flow variations, it is common practice to install a surge tank of sufficient capacity to accommodate any flow variation.

2) *Concentration Equalisation*

Possible concentration variations in the spill can cause premature column leakage and breakthrough (Slejko, 1985). This problem is also handled with a surge tank in the same manner as for flow equalisation.

3.4.3 Flow Control & Monitoring

Flow control and monitoring of the spill through the adsorption unit will be required in order to balance flows in a multiple column configuration. This will be achieved by the use of valves and flowrate transducers. A dosing pump is to be used to move the spill from the spill containment vessel through the G.A.C. adsorption columns.

3.5 Portable Carbon Adsorption Unit System Overview

Figure 9 below outlines the portable carbon adsorption unit sytem in its four major units.

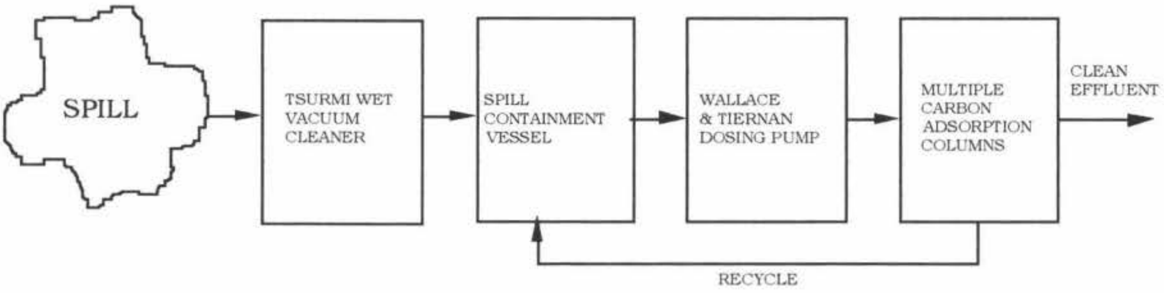


Figure 9. Adsorption Unit System Overview

Tsurumi Wet Vacuum Cleaner:	-removes spill from spill site.
Spill Containment Vessel:	-provides flow and concentration equalisation.
Dosing Pump:	-moves contained spill through the carbon adsorption columns at a controlled flowrate.
Multiple GAC Adsorption Columns:	-Upflow fluid flow through columns, which can be operated in either series or parallel configurations.

3.6 Materials Selection

When deciding on the materials to use in the design of an adsorption system, the following considerations must be taken into account:

1) Type of spill/influent that is to be processed by the system.
2) Type of adsorbent that is to be used.
3) Composition of the regenerant (if the system allows for this).
4) Cost of materials.
5) Ease of construction/fabrication.
6) Mechanical requirements.

The above will determine the type of materials that can be used in the construction of the adsorption columns and the pipe work system. There are a number of variables that need to be taken into account and also their effect on the selection of materials. Table 5 below outlines the variables and their effects.

Table 5. Design Variables Affecting Materials Selection

Variable	Effect on Materials Selection
Spill/influent will be of variable type and concentration.	Material used in the construction of columns and pipe work will be required to withstand a wide range of chemical environments.
Granular Activated Carbon adsorbent is to be used.	Activated Carbon is highly corrosive to some materials, especially carbon steel or mild steel.
Composition of the regenerant stream.	This is not a consideration for the portable adsorption unit as regeneration of the carbon will not be carried out on-line.
Ease of construction / fabrication and assembly of unit.	Choose materials that are easy to machine and do not require specialised fabrication techniques in order to keep the cost of construction down. Especially important, as the unit is a prototype.
Adsorption unit is to be portable and capable of being handled by two people.	Materials selected should preferably be lightweight, but having the required mechanical properties.
Mechanical Requirements	Columns and pipe work will be subjected to variable hydrostatic pressures.

3.6.1 Materials Selected

The following table gives the type of materials selected for the major components of the portable adsorption unit.

Table 6. Adsorption Unit Materials

Component:	Material Selected:	Decision Basis:
Adsorption Columns	UPVC pressure pipe cut into lengths. PVC sheet for fabrication into end caps.	PVC is able to withstand a reasonably wide range of chemicals (refer to *Guide to Chemical Resistance of Thermoplastic and Elastomeric Materials*).
Pipe work and fittings	UPVC pressure pipe and fittings.	As above. Easy to assemble.
Surge Tank	Grade 316 Stainless steel.	Highly resistant to a wide range of chemicals. Easy to fabricate.
Support Structure	Aluminium rectangular hollow sections .	Lightweight while providing the necessary structural strength. Resistant to a wide range of chemical attack.

4.0 DETAILED DESIGN

4.1 Definition

A final concept for the portable carbon adsorption unit has now been defined. Detailed design will be concerned with the design of those elements identified in the conceptual design (refer to Chapter 3), namely the design of the columns, associated pipe work and the supporting structure, selection of the appropriate pump and flow rate transducers.

4.2 Column Design

The key design parameter in adsorption systems is flowrate, or its reciprocal, residence time. This parameter establishes the on-line adsorbent volume and the sizing of the adsorption columns. However, flowrate is constrained by a number of other parameters; the desired treatment objective (leakage level), capacity, column throughput and regeneration frequency. These parameters in turn will be very much dependent upon the type, concentration and size of spill to be treated. Therefore, column design will not merely be a case of optimising for a specific adsorbate, but instead designing columns that are capable of meeting the variable nature of chemical spills, as well as keeping in mind that the final unit must meet the design criteria given in Chapter 3, section 3.2.1.

4.2.1 Column Design Variables

There are a number of design variables which must be considered in the design of a fixed bed G.A.C. adsorption column. These being as follow:

A) Upflow Fluid Velocity

Upflow fluid velocity must not be so high as to cause fluidisation of the packed bed. Fluidisation will cause attrition of the G.A.C.. Upflow velocities in packed beds are typically limited to 80% of the fluidisation velocity (Ruthven, 1984).

B) Pressure Drop

Pressure drop across a packed bed will increase with flowrate and can lead to flow channelling. Increased pressure drops also place extra pressure requirements on pumps and other fluid handling equipment.

C) Hydraulics

Ideally, the influent should be dispersed, distributed and flow as uniformly over and through the bed, and flow uniformly through the bed, contacting each particle of adsorbent at a uniform rate. However, several researchers (Vortmeyer, 1985) have shown that column diameter to particle diameter ratios greater than 21 do not give rise to wall effects.

D) Portability

Columns should be of a size that can be easily and safely handled by one person. The overall height of the adsorption unit in part will be determined by the column height, the associated pipe work and the fluid control equipment. The total height of the unit must not be overly high as to cause lateral instability of the unit.

4.2.2 Design Steps to Determine Column Diameter and Packed Bed Height

The following is an outline of the steps taken to determine the size of adsorption columns to be used.

STEP 1: Determine the minimum fluidising velocity for Granular Activated Carbon.

The minimum fluidisation velocity can be determined by the following equation which is based on the Carman-Kozeny equation:

$$U_{mf} = 0.0055 \frac{e^3_{mf}}{1 - e_{mf}} \frac{d^2(\rho_s - \rho)g}{\mu}$$

For G.A.C. the minimum fluidisation velocity was determined to be 0.795 m/min. (refer to Appendix A5). Ruthven has suggested that upflow velocities in columns be kept to 80% of minimum fluidisation velocity. Therefore 80 % of Umf = 0.61m/min (maximum upflow velocity).

STEP 2: **Determine packed bed upflow velocities for varying flowrates and column diameters.**

Figure 10 below shows the relationship between column/packed bed diameter and resultant upflow velocity for various flowrates.

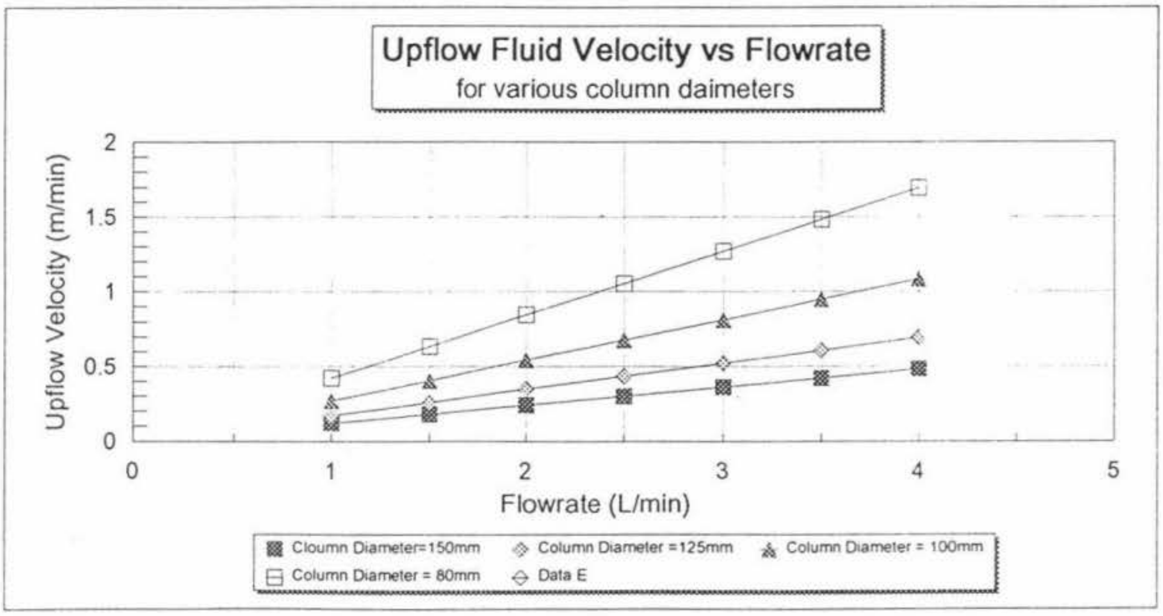


Figure 10. **Upflow Fluid Velocity Versus Flowrate For Various Column Diameters**

It can be seen from the above graph that increasing the column/packed bed diameter increases the possible volumetric flowrate through the bed without causing fluidisation of the bed. Conversely, as the column diameter is reduced, so too are the allowable volumetric flowrates as velocities in the column become greater than the minimum fluidisation velocity.

However, as the bed area is increased so too is the pressure drop across the bed. This is shown in figure 11.

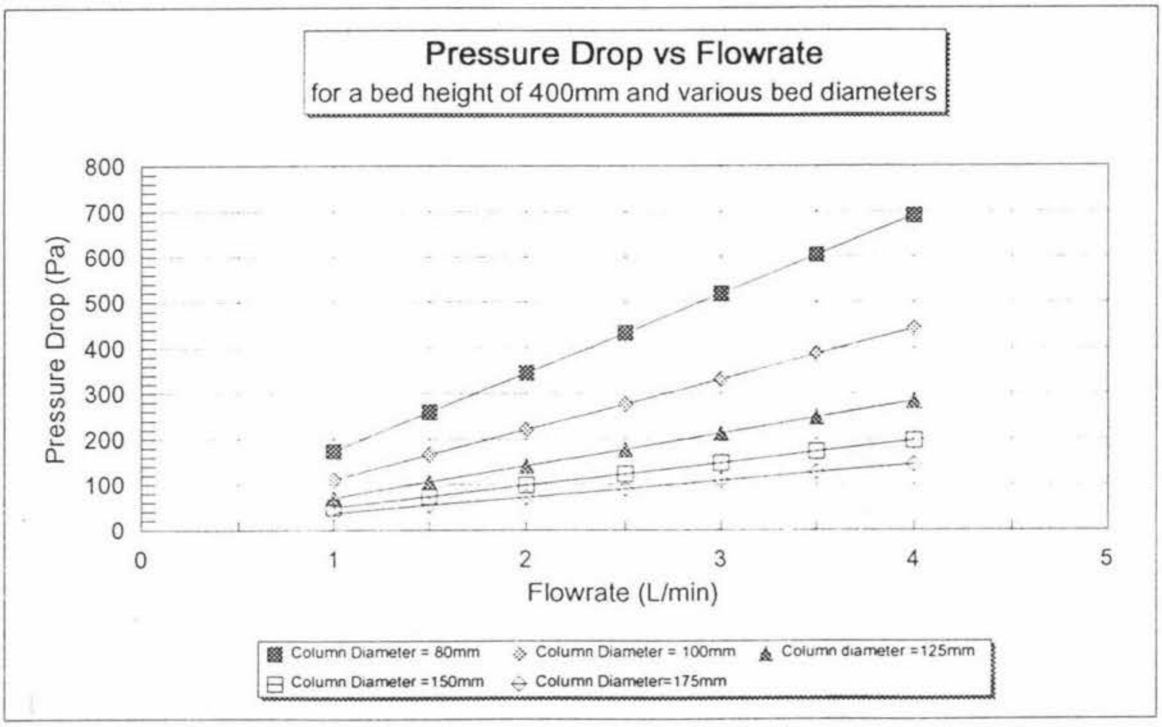


Figure 11. **Pressure Drop Versus Flowrate**

STEP 3: Determine the effect of varying packed bed lengths on pressure drop

Pressure drops across varying lengths of packed bed at the chosen column diameter of 125mm were calculated using the correlation given by Leva [*Fluidisation,* 1959] (refer to appendix A6). Figure 12 below shows the relationship between varying packed bed lengths and the resultant pressure drop over a range of flowrates.

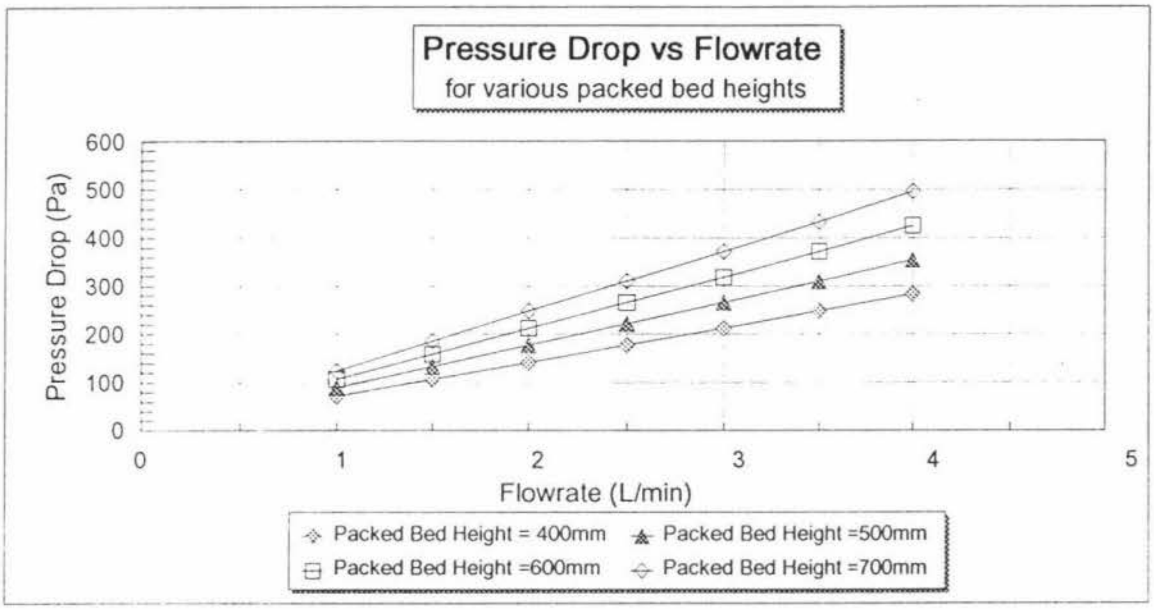


Figure 12. Pressure Drop Versus Flowrate For Various Packed Bed Heights

Figure 12 clearly shows that a change in packed bed length has a marked effect on pressure drop within the column. While these pressure drops may seem insignificant by themselves, it must be remembered that the column forms only part of the total system. The total pressure drop across a system of multiple adsorption columns, flow meters, valves and pipes will be quite significant. Therefore, it is of great value to determine the effect a single column will have on the systems pressure drop.

STEP 4: Determine the effect of varying column diameters and flowrates on influent residence time for a fixed bed length.

Residence time of the influent in the packed G.A.C. will be greater for lower flowrates and larger column diameters. This is shown in figure 13 below. However, it is interesting to note that the residence time of the influent drops off steeply up to flowrates of approximately 2.5 L/min after which further increases in flowrate have a less pronounced effect on influent residence time.

Residence time will have a direct effect on the length of the M.T.Z. (Slejko, 1985). When water or other low viscosity fluids flow through the bed at a very rapid rate decreasing influent residence time, the M.T.Z. will become long and drawn out, and will result in a breakthrough curve that will begin to leak contaminant very early on, and complete breakthrough will not be achieved for a long time in the bed.

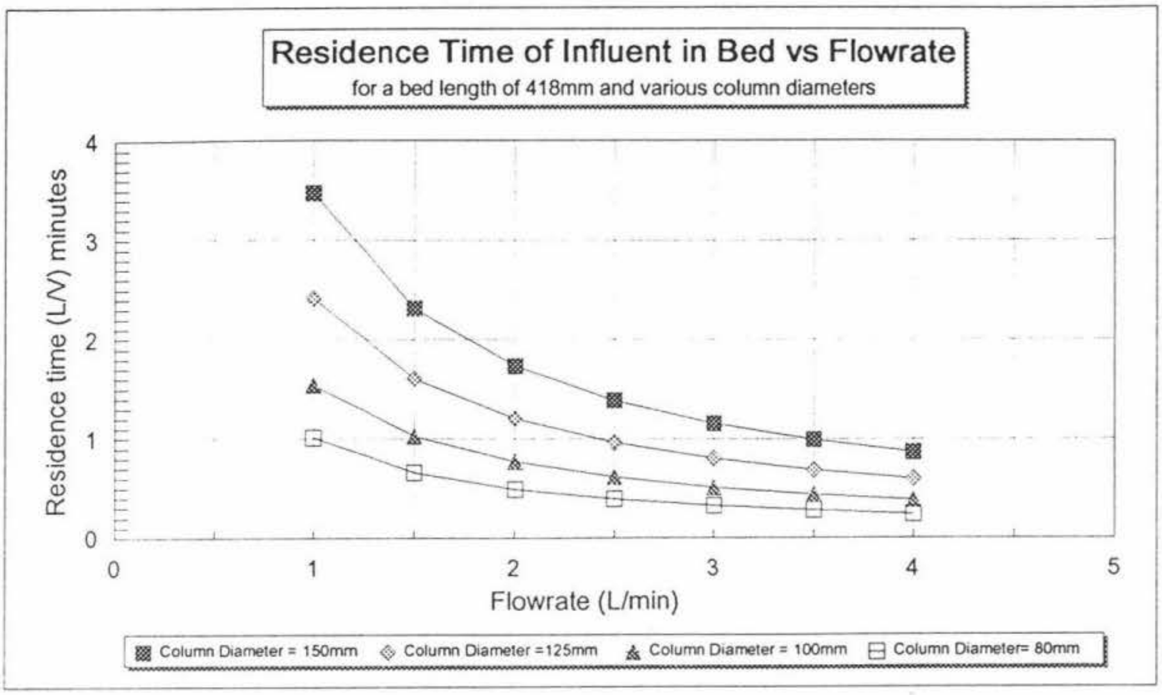


Figure 13. **Residence Time of Influent in Bed Versus Flowrate**

STEP 5: Select column diameter and packed bed height.

Based on the design criteria given in 3.2.1 and the data obtained through steps 1 - 4, a column diameter of 125mm (nominal bore) and a packed bed height of 400mm was selected. A column diameter of 125mm allows the bed to operate up to a maximum flowrate of 4 L/min compared to maximum flowrates of 1.5 and 2.5 L/min for column diameters of 80 and 100 mm respectively. Pressure drops across a packed bed of 400mm range from approximately 70 - 290 Pa over the 1 - 4 L/min influent flowrates.

4.2.3 Prediction of Influent Breakthrough using the Equilibrium Model

The simplest model for predicting breakthrough time is the equilibrium model. If the effect of mass transfer resistance is neglected, then a vertical wave front is formed and its breakthrough time at column length, L, can be determined by column capacity, as follows:

$$t_w = \frac{W_s \, L \, Q_e}{V \, \varepsilon_b \, C_o}$$

(Noel et al., 1992)

This model was applied in predicting the breakthrough times for four different influents 2,4-D, PCP, Phenol, and Cr^{3+} at influent concentrations of 100 - 1000 mg/L. and flowrates of 1 - 4 L/min. for the column dimensions specified in STEP 5 of 4.2.2. All four influents used have adsorption isotherms which are able to be described by the Freundlich model. Tables 7 and 8 show how variations in concentration and flowrate of the influent affect breakthrough time for the size of column selected. As is to be expected increasing influent concentrations and/or flowrates give rise to earlier influent breakthrough. While the equilibrium model only predicts approximately the appearance time of the breakthrough curves, it is useful in this stage of design to establish the number of columns required for the portable adsorption unit and the length of time to be expected for experimental trials in order to evaluate the performance of the columns.

Breakthrough Times for 2,4-D at varying Concentrations Flowrates							
Flowrate (l/min)	1	1.5	2	2.5	3	3.5	4
Influent Conc (mg/l)			Time for Breakthrough (hours)				
100	35.484	23.656	17.742	14.193	11.828	10.138	8.871
150	27.821	18.547	13.911	11.128	9.274	7.949	6.955
200	23.410	15.607	11.705	9.364	7.803	6.689	5.853
250	20.477	13.651	10.238	8.191	6.826	5.851	5.119
300	18.355	12.237	9.178	7.342	6.118	5.244	4.589
400	15.445	10.297	7.723	6.178	5.148	4.413	3.861
500	13.510	9.006	6.755	5.404	4.503	3.860	3.377
600	12.110	8.073	6.055	4.844	4.037	3.460	3.027
700	11.040	7.360	5.520	4.416	3.680	3.154	2.760
800	10.190	6.793	5.095	4.076	3.397	2.911	2.548
900	9.495	6.330	4.747	3.798	3.165	2.713	2.374
1000	8.913	5.942	4.457	3.565	2.971	2.547	2.228
Breakthrough Times for Cr3+ at varying Concentrations Flowrates							
Flowrate (l/min)	1	1.5	2	2.5	3	3.5	4
Influent Conc (mg/l)			Time for Breakthrough (hours)				
100	7.548	5.032	3.774	3.019	2.516	2.156	1.887
150	6.015	4.010	3.007	2.406	2.005	1.718	1.504
200	5.120	3.413	2.560	2.048	1.707	1.463	1.280
250	4.518	3.012	2.259	1.807	1.506	1.291	1.130
300	4.080	2.720	2.040	1.632	1.360	1.166	1.020
400	3.473	2.315	1.736	1.389	1.158	0.992	0.868
500	3.065	2.043	1.532	1.226	1.022	0.876	0.766
600	2.767	1.845	1.384	1.107	0.922	0.791	0.692
700	2.538	1.692	1.269	1.015	0.846	0.725	0.635
800	2.355	1.570	1.178	0.942	0.785	0.673	0.589
900	2.205	1.470	1.103	0.882	0.735	0.630	0.551
1000	2.079	1.386	1.039	0.832	0.693	0.594	0.520

Table 7: Breakthrough Times Calculated Using the Equilibrium Model for 2,4-D and Cr3+

Breakthrough Times for Phenol at varying Concentrations & Flowrates							
Flowrate (l/min)	1	1.5	2	2.5	3	3.5	4
Influent Conc (mg/l)			Time for Breakthrough (hours)				
100	68.250	45.500	34.125	27.300	22.750	19.500	17.063
150	47.963	31.975	23.981	19.185	15.988	13.704	11.991
200	37.343	24.895	18.671	14.937	12.448	10.669	9.336
250	30.754	20.502	15.377	12.301	10.251	8.787	7.688
300	26.243	17.495	13.121	10.497	8.748	7.498	6.561
400	20.432	13.621	10.216	8.173	6.811	5.838	5.108
500	16.827	11.218	8.413	6.731	5.609	4.808	4.207
600	14.359	9.572	7.179	5.743	4.786	4.102	3.590
700	12.557	8.371	6.278	5.023	4.186	3.588	3.139
800	11.179	7.453	5.590	4.472	3.726	3.194	2.795
900	10.091	6.727	5.045	4.036	3.364	2.883	2.523
1000	9.207	6.138	4.603	3.683	3.069	2.630	2.302
Breakthrough Times for PCP at varying Concentrations & Flowrates							
Flowrate (l/min)	1	1.5	2	2.5	3	3.5	4
Influent Conc (mg/l)			Time for Breakthrough (hours)				
100	128.814	85.876	64.407	51.526	42.938	36.804	32.204
150	91.893	61.262	45.946	36.757	30.631	26.255	22.973
200	72.311	48.208	36.156	28.925	24.104	20.660	18.078
250	60.045	40.030	30.023	24.018	20.015	17.156	15.011
300	51.585	34.390	25.792	20.634	17.195	14.739	12.896
400	40.593	27.062	20.296	16.237	13.531	11.598	10.148
500	33.707	22.471	16.854	13.483	11.236	9.631	8.427
600	28.958	19.305	14.479	11.583	9.653	8.274	7.239
700	25.468	16.979	12.734	10.187	8.489	7.277	6.367
800	22.787	15.191	11.394	9.115	7.596	6.511	5.697
900	20.658	13.772	10.329	8.263	6.886	5.902	5.164
1000	18.922	12.615	9.461	7.569	6.307	5.406	4.730

Table 8: Breakthrough Times Calculated Using the Equilibrium Model for Phenol and PCP

4.2.4 Adsorption Column Construction

As specified in section 3.6 the materials of construction for the columns is unplasticised P.V.C.. It was chosen due to its ability to withstand a reasonably wide range of chemicals, its ability to be easily machined and the material is of a low cost, which is an important factor in a prototype construction. The column design and its basic componentry are shown on page 78.

1) *Adsorption Column Body*

The adsorption column body is constructed from a 500mm section of Class C uPVC pressure pipe, which is capable of withstanding hydrostatic working pressures of up to 900 kPa, and has excellent impact resistance qualities.

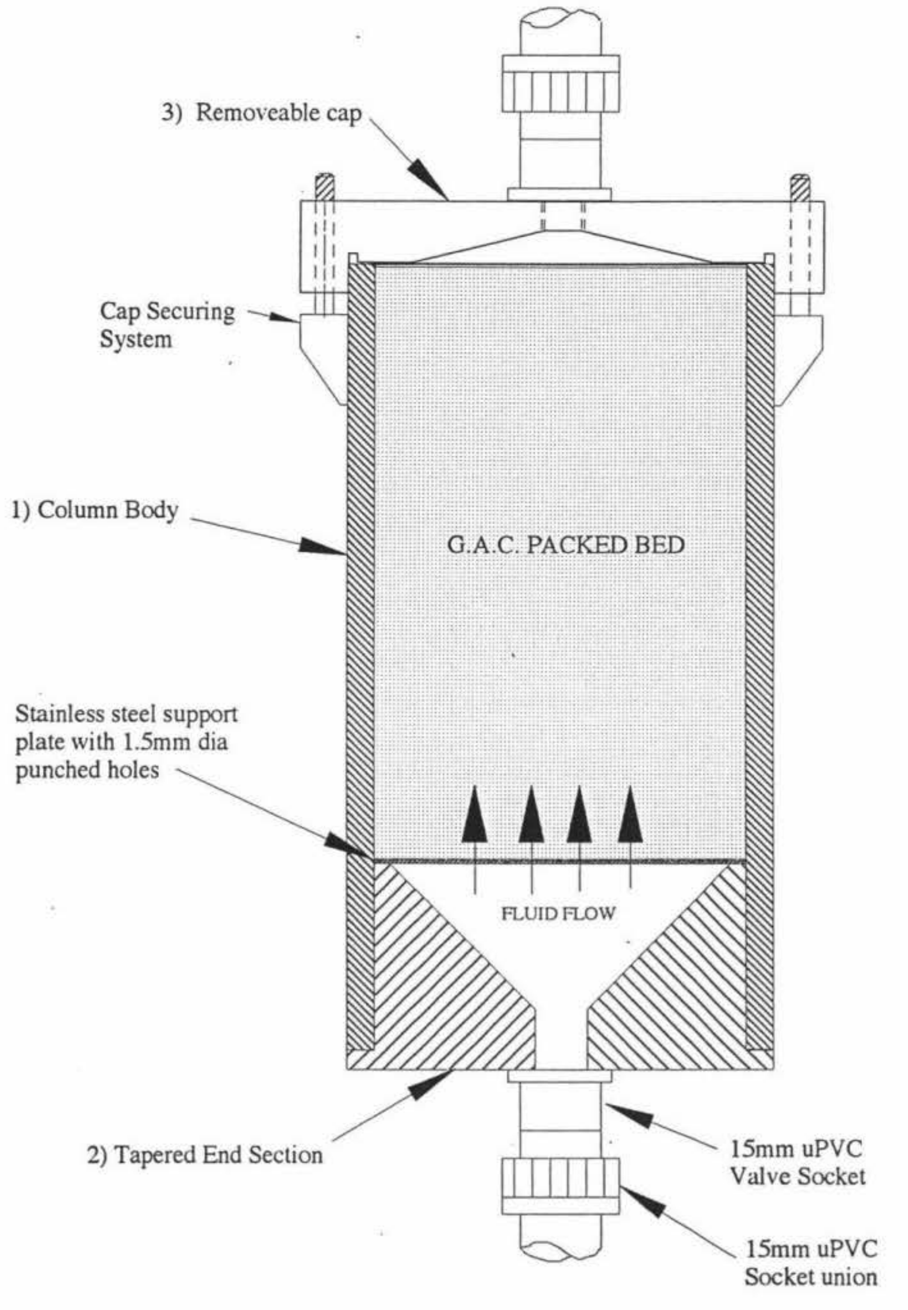
2) *Tapered End Section*

The tapered section of the column serves to distribute the influent evenly across the base of the packed bed so as to ensure uniform contact of the influent with every section of the packed bed. The taper also reduces the pressure drop created from the fluid exiting the pipe and entering the column. On top of the tapered section sits a Grade 316 stainless steel plate (125mm diameter) with punched holes 1.5mm in diameter at 3mm spacings. On top of the punched stainless steel plate is a wire mesh (125mm diameter, 0.5mm gauze). The punched plate supports the packed bed, while the mesh prevents any G.A.C.

falling back through the system. Construction details for the tapered section are given in drawing No: AC/3 in Appendix B3.

3) *Removable Cap*

The cap provides a means of access for the removal of spent G.A.C. and replacement with fresh G.A.C. or other adsorbents if so desired. The cap is sealed using an O-ring system and is secured in place using three positively located clamping positions. The cap also features a tapered section on the under side in order reduce pressure drops caused by the fluid exiting. Construction details for the cap and securing system are given in drawings AC/1 and AC/2 of Appendix B1 and B2 respectively.



Socket Union connects to uPVC ball valve and turbine type flowmeter

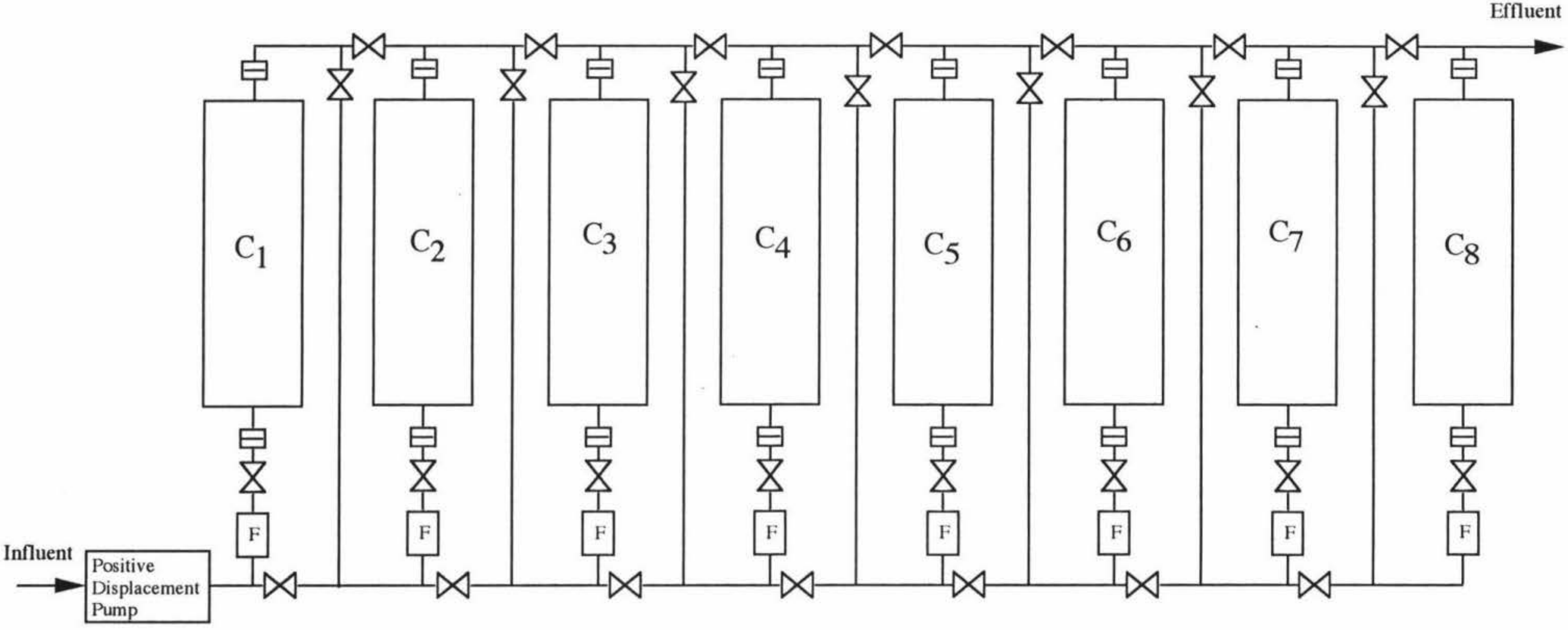
ADSORPTION COLUMN CONSTRUCTION

NOT TO SCALE

4.3 Multiple Adsorption Column System Configuration

In the conceptual design of the portable carbon adsorption unit, it was decided that multiple G.A.C. adsorption columns are to be used, and that they are to be arranged in such a way that the columns are capable of operating in either parallel or series modes or a combination of both. The operating arrangement of the columns being dependant on the type of spill being treated and the desired treatment objective.

What now remains to be decided upon is the number of columns required to make up the system. Again, due to the variable nature of spill treatment, it is not possible to determine the ideal number of columns required. For the purposes of this prototype design a total of eight columns was decided upon, arranged in the manner shown overleaf (refer to "Portable Adsorption Unit Schematic").on page 80. The number of columns chosen allows for several different configurations of parallel or series mode operation or both. The system also has the capability of removing spent adsorption columns while still remaining in operation.



KEY

C_1-C_8 Adsorption Columns

⊟ Coupling

F Flow meter (1-10 L/min)

⋈ Ball Valve

Notes:

Fluid flow through columns is up-flow.
Series or parallel column configurations available.

TITLE: PORTABLE ADSORPTION UNIT SCHEMATIC

DRAWN BY: M.W. Hynes	Not to Scale	DATE:- 9/10/92

4.3.1 System Features

1) *Column Flowrate Control and Monitoring*

Influent flow in each column is controlled through the use of a uP.V.C. ball valve and a turbine type flowmeter. The flowmeter chosen is a GPI electronic digital meter, in which the turbine housing and LCD display unit are contained as one unit. The meter is specified for flowrates of 1 - 10 L/min. The maximun pressure drop across the metre being 13.78 kPa at 10 L/min.

2) *Series/Parallel Column Operational Configurations*

Columns can be operated in either a series or parallel configuration, or both. This is achieved by the switching of the appropriate uPVC ball valves.

3) *Individual Column Isolation and Removal*

Each column is capable of being isolated and removed from operation while the rest of the unit is still in service - this usually being required when the G.A.C. in the column is spent and requires replacement with fresh G.A.C.. Again this is achieved by switching of the appropriate ball valves.

4) *Variable Speed Influent Pumping*

Influent is driven through the columns by the use of a variable speed diaphragm metering pump. The pump chosen is a Lewa ecodos diaphragm pump capable of pumping at 750 L/hr (12.5 L/min) and delivering operating pressures of up to 5 bar (500 kPa). The pump features a P.V.C. pump head and PTFE sandwich diaphragm which are suitable for handling a wide range of chemicals. Any pulsations caused by pumping are prevented by the use of a pulsation damper. Speed control is achieved by changing the stroke length of the diaphragm through a linear graduate handwheel.

5) *Process Piping and Fittings*

All process piping and fittings consists of 15 mm nominal bore class E uPVC pressure pipe and fittings.

6) *Spill Containment Vessel*

A stainless steel (Grade 316) 60 litre spill containment vessel provides equalisation of flow and concentration of the influent prior to being processed (refer to section 3.4.2).

7) *Effluent Recycle*

An effluent recycle line is provided in case the treatment objective has not been met prior to discharge. Any effluent that does not meet discharge requirements can be recycled back into the spill containment vessel for further processing.

8) *Sampling Ports*

Sampling ports are located at the discharge end of each column and are shown in figure 14. This allows the adsorption process to be monitored as it progresses, identifying columns that are exhausted of adsorption capacity and how many columns are needed on-line at any on time to treat the spill.

9) *Spill Removal Unit*

Spills are removed from the spill site by the use of a Tsurumi Wet Vacuum Cleaner which transfers it into the adsorption unit's spill containment vessel or other containment vessel if required. The unit has a maximum displacement capacity of 45 L/min. (refer to appendix C1 for the Tsurumi Wet Vacuum Cleaner instruction manual).

10) *Portability*

The complete unit i.e. adsorption columns, spill containment vessel, and Tsurumi Wet Vacuum Cleaner are located on a fully portable framework (refer to appendix B4 for framework design). The complete unit is 2.05 metres long and 0.614 metres wide, thus enabling the unit to be manouvereed through a standard doorway. See figures 15 and 16 for the fully assembled unit.

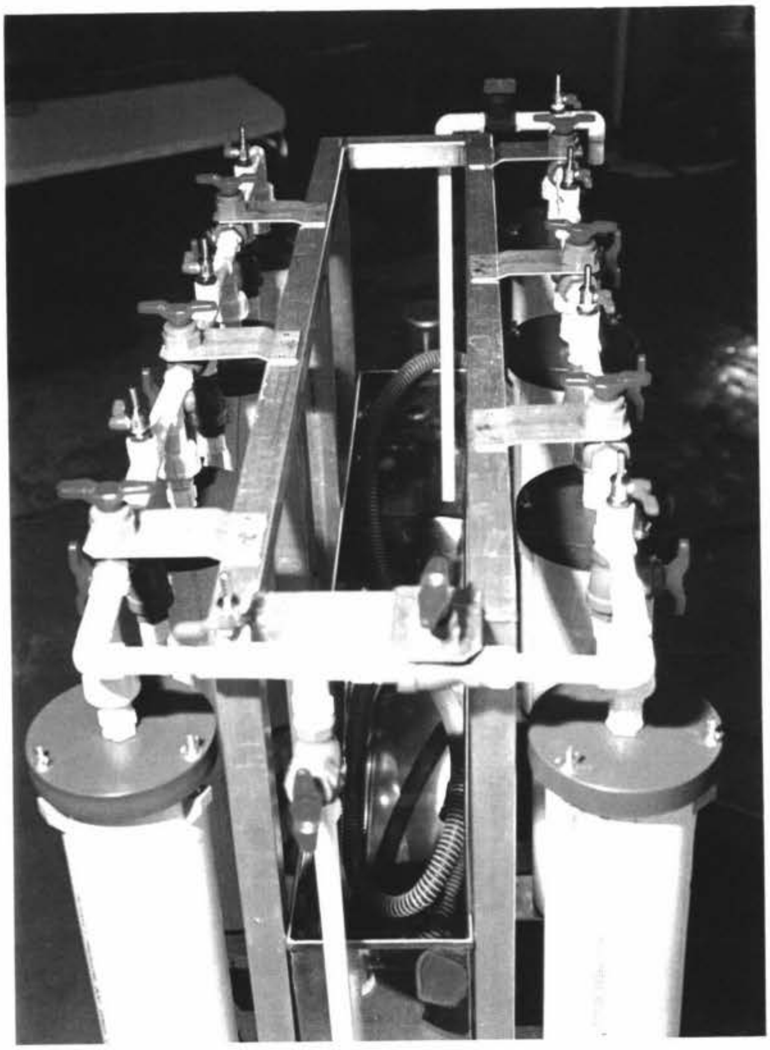
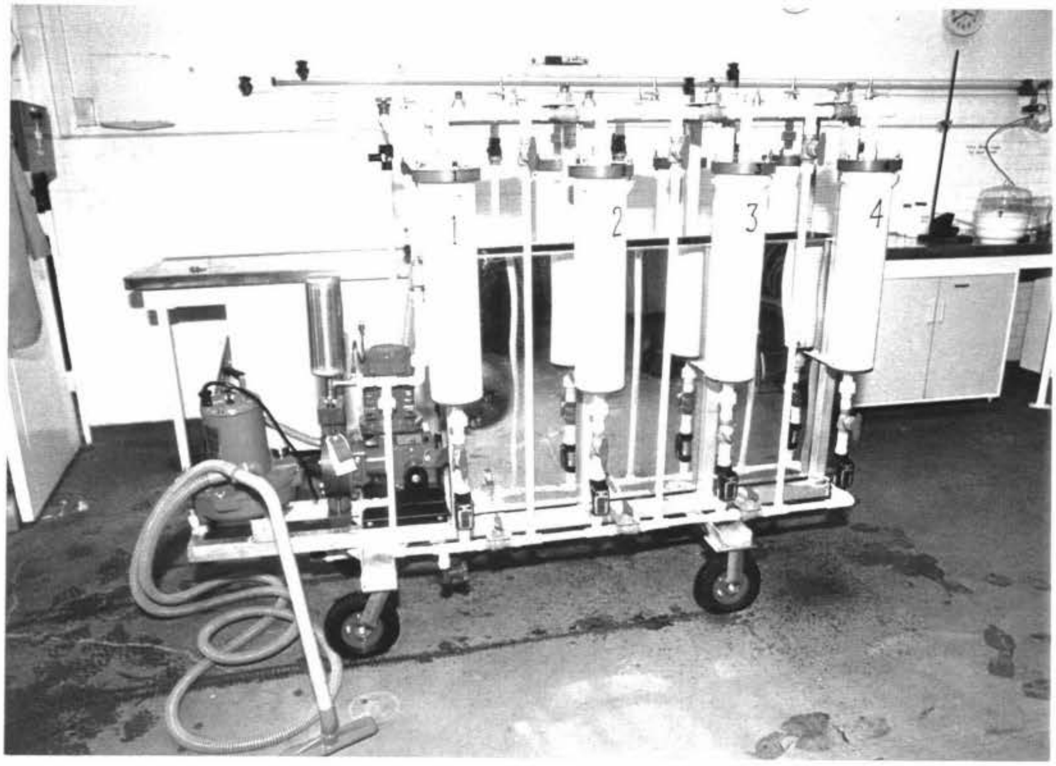


Figure 14. Overhead View of Adsorption Unit Showing the Sampling Ports Used to Monitor the Progress of Influent Treatment



Figures 15 and 16. Fully Assembled Prototype Portable Adsorption Unit

5.0 COLUMN PERFORMANCE

5.1 Introduction

After the portable adsorption unit had been constructed, a series of experiments were carried out in order to determine the performance of an individual column on the unit. The experiments consisted of running 2,4-D influent of various concentrations through the column at differing flowrates until a pre-determined breakthrough point was achieved. In this case the breakthrough point chosen was when the effluent concentration reached 10% of the influent concentration, i.e when C/Co = 0.1. The chosen column operating conditions are shown in table 9 below.

Table 9. Column Operating Conditions

Influent Conc (mg/L)	Flowrate (L/min)	Residence Time (s)	Estimated Column Exhaustion Time	Influent Req to Exhaust Column (litres)
100	3	46.14	11.8	1980
200	1.5	92.28	15 hrs	1350
300	2	69.21	9 hrs	1101
400	3	46.14	5.1 hrs	918

A treatment objective of C/Co = 0.1 was primarily chosen due to the large amounts of influent that would be required to be made up in order to run a column to complete exhaustion, i.e C/Co = 1.

5.2 Experimental Procedure

The single column adsorption experiments were carried out using Calgon Corp granular activated carbon of the 850-1400μm diameter, while 2,4-D with a greater than 98% purity was supplied by Dow Elanco Ltd, New Plymouth, New Zealand. The concentration of the 2,4-D was measured using a Varian series - 634 UV spectrophotometer at 284.1 nm and 1 cm path length.

The following procedure was followed in the column experiments:

1) A standard curve for 2,4-D up to 400mg/L for determining U.V. spectrophotometer measurements was determined.

2) Stock solutions of 5000ppm 2,4-D were made up and diluted to the required concentration in 50 litre drums.

3) The pH of the solution contained in the 50 litre drum was adjusted to 6.5 using concentrated HCL.

4) The fresh G.A.C. in the column was wet by running water through the column for 20 minutes.

5) The drummed solution was transferred into the portable adsorption units spill containment vessel by use of the Tsurumi Wet Vacuum Cleaner.

6) The influent was pumped through the column at the required flowrate as set out in table 10.

7) Adsorbence measurements of the effluent were taken 10 minutes after startup to ensure there was no detectable 2, 4-D in the effluent at such an early stage.

8) Adsorbence measurements were then taken every 30 minutes until detection of 2, 4-D in the effluent. On detection of 2, 4-D, adsorbence measurements were then taken every 12 minutes until 1% of the influent concentration was reached in the effluent. After this time adsorbence measurements were taken every 30 minutes until $C/Co = 0.1$. Experiments stopped at $C/Co = 0.1$.

5.3 Results and Discussion

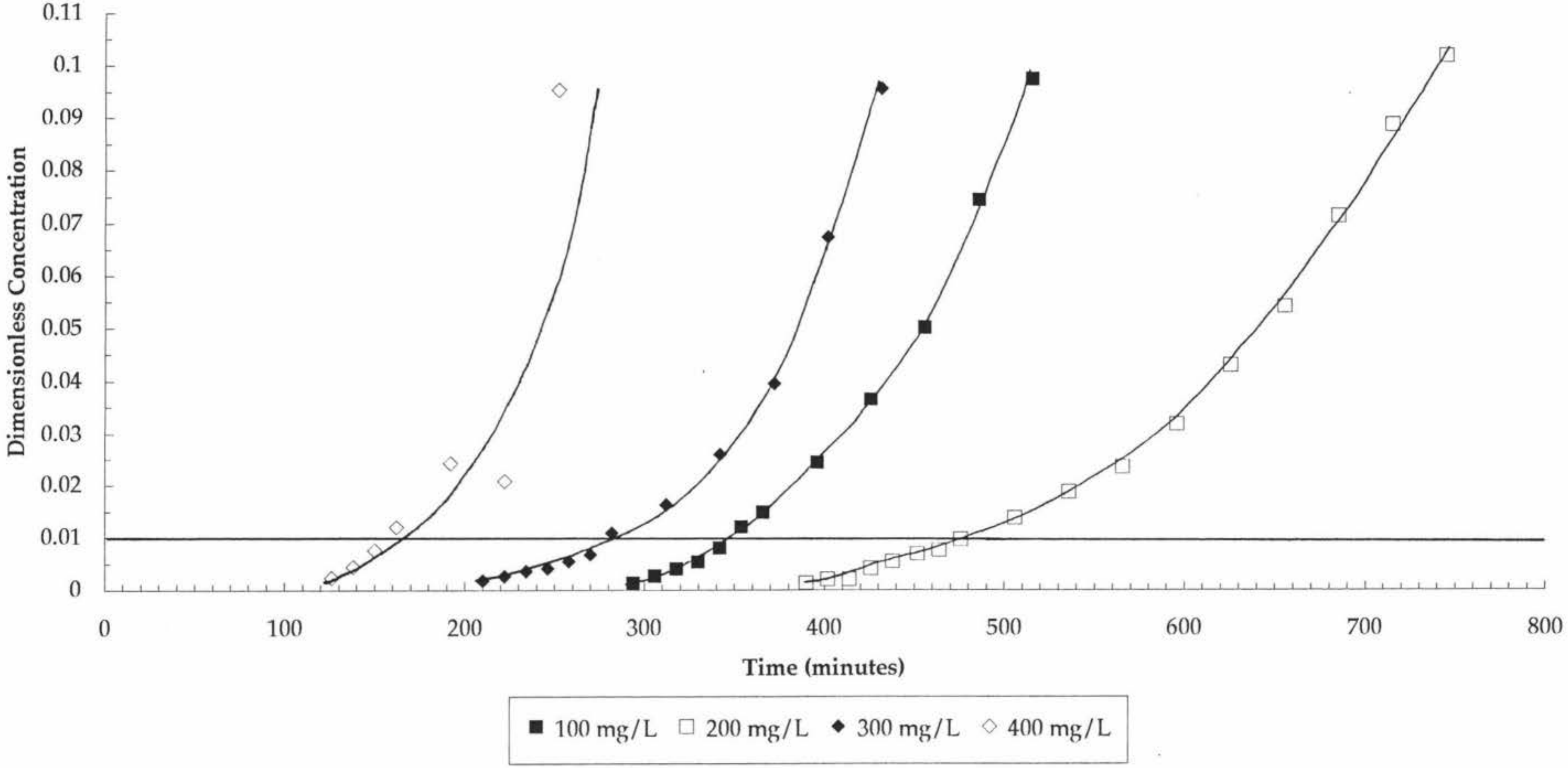
The experimental data were plotted as breakthrough curves in the form of dimensionless concentration against time to process the influent. The breakthrough curves obtained for all four adsorption experiments are shown in figure 17 on page 90. The data obtained clearly shows the effects that the influent velocity and concentration have on the appearance of the breakthrough curve, both the resulting shape of the curve and the length of time before it appears. For the case of a desired treatment objective of $C/Co = 0.01$

the time of appearance of the breakthrough curves for each experimental condition were as follows (see Table 10 below).

Table 10. Breakthrough Times and Volumes of Influent Treated at C/Co = 0.01

Influent Conc (mg/L)	Flowrate (L/min)	Residence Time (seconds)	Breakthrough Time at C/Co=0.01	Volume of Influent Treated (L)
100	3.0	46.14	350	1050
200	1.5	92.28	485	727
300	2	69.21	285	570
400	3	46.4	158	474

Figure: 17 Breakthrough Curves for Various Operating Conditions of a Single G.A.C. Adsorption Column



It can be seen from figure 17 that higher influent flowrates tend to give rise to a steeper breakthrough curve and earlier breakthrough times. This is to be expected, as increased flowrates give rise to an increase in superficial velocity through the packed bed. This in turn reduces the effective contact time of the influent with the Granular Activated Carbon, therefore reducing the amount of pollutant that can be adsorbed onto the carbon. The steepness of the breakthrough curves at higher flowrates can be attributed to external mass transfer resistance (Noll et al., 1990). The resistance to external mass transfer is smaller when flowrates are higher, so that the length of the mass transfer zone is reduced and a sharper breakthrough curve is generated.

It is also interesting to note that influent concentration also effects the shape and time of appearance of the breakthrough curve. With higher influents, concentrations tend to give a steeper curve compared to influents with a lower concentration, for example.the 400mg/L breakthrough curve is steeper compared with the 100mg/L breakthrough curve. Both have the same flowrate of 3 L/min. Noll (1990) states that this is evidence that interparticle diffusivity varies with liquid concentration.

The quantities of influent that were capable of being treated to a treatment objective of C/Co = 0.01 are considerably higher than the required 200 litres given in the project design brief. However, the time to process a 200 litre spill of the type found in the column trials will take from 66 - 133 minutes for a single column. This time could be further reduced by running two or more columns in parallel with each other. For example, the processing time for 200 litres of a 200 mg/L solution of 2, 4-D running through two columns in parallel at flowrates of 1.5 L/min until an effluent concentration of 2 mg/L was reached, would be 66 minutes compared with 133 minutes for a single column. It is, therefore, obvious that the current eight column arrangement for the adsorption unit provides a good level of flexibility in terms of being able to decrease the time required to process a spill while still maintaining the treatment objective. The unit also shows the capability to process larger spill quantities than the 200 litres required by the design brief and still maintain acceptable low levels of pollutant in the effluent.

5.4 Conclusion

Performance evaluation of a single column in the Portable Adsorption Unit has shown that a single column is capable of providing adequate treatment of a 2,4-D spill of varying concentrations and under varying flowrate conditions. The evaluation also shows that the design requirements to process spills of at least 200 litres in size can be easily met. The unit's ability for its columns to configured in either parallel or series mode of operation, also allows the times for spill processing to be decreased considerably while still being able to maintain the desired treatment objective.

SUMMARY

The use of Carbon Adsorption Technology for the treatment of toxic chemicals spills is well-established in the U.S.A.. However, to date this technology has not yet been applied in New Zealand for this purpose. It is felt that this technology could be successfully applied in New Zealand for the treatment of toxic chemicals, however, it would only be required on a small scale. For this reason it was decided to design and build a small scale portable adsorption unit in order to evaluate the whole concept.

A conceptual design was carried out to determine the units process configuration. This conceptual design stage revealed that the portable adsorption unit would consist of four basic units. These being 1) a Tsurumi wet vacuum cleaner for removal of the spill from the spill site, 2) a spill containment vessel for influent flow and concentration equalisation, 3) a dosing pump for controlled pumping of the contained spill through the G.A.C. adsorption columns, 4) and multiple G.A.C. adsorption columns. These columns are capable of operating in either parallel or series modes or a combination of both, the operating arrangement of the columns being dependent upon the type of spill being treated and the desired treatment objective. Fluid flow through the individual columns is 'upflow' due to the greater contact time between the G.A.C. and the influent, giving greater pollutant removal compared to a 'downflow' configuration. Detailed design of the system concentrated on the design of the columns, associated pipe work, supporting structure, and the selection of the appropriate pump and flow rate transducers.

Evaluation of the final units performance was achieved by carrying out a number of adsorption experiments on a single column. The influent used was 2,4-D, made up at concentrations between 100 - 400 mg/L, and pumped through the column at varying flowrates until the effluent concentration reached 10% of the influent concentration, i.e $C/Co=0.1$. This evaluation showed that a single column was able to treat at least 470 litres of 2,4-D influent at maximum flowrate and concentration conditions. The unit therefore shows the potential to process spills of varying size and concentration within reasonable short periods of time.

BIBLIOGRAPHY

Arbuckle, B. & Ho, Y.F. (1990). Research notes: Adsorber Column: Principle Diameter Ratio Requirements. *Research Journal WPCF, 62,* no1.

Bhuskar, G.V. & Bhamidimarri, R.S.M. (1992). Adsorption of 2, 4-D onto Activated Carbon: Application of Nth Order Approximation. *Journal of Chem. Tech. Biotechnology,* 53, 297-300.

Blum, D.J.W., Suffet, I.H. & Duguet, J.P. (1993). Estimating the Activated Carbon Adsorption of Organic Chemicals in Water. *CR in Environmental Science and Technology, 23,* Issue 2, 121-136.

Cheremisinoff, P.N. & Ellerbusch, F. (1980). *Carbon Adsorption Handbook.* Michigan: Ann Arbor Science Publishers, Inc.

Cooney, D.O. (1991). Determining External Film Mass Transfer Coefficients for Adsorption Columns. *Journal AICHE, 37,* no8, 1270:1273.

Coulson, J.M., Richardson, J.F., Backhurst, J.R. & Harker, J.H. (1991). *Chemical Engineering.* 2, (4th ed.). Oxford: Pergamon Press, Inc.

Crittenden, J.C., Hand, D.W., Arora, H. & Lykins Jr, B.W. (1987). Design Considerations for G.A.C. Treatment of Organic Chemicals. *Journal AWWA,* January, 74-82.

Fingas, M.F., Stone, M., Leblanc, D., Sergy, G., Mansfield, B.H. et al. (1990). Development of a New Chemical Spill Priority List. Environment Canada, Ottawa, Ontario. *Proceedings of the Seventh Technical Seminar on Chemical Spills, June 4-5, 1990.*

Freeman, H.M. (1989). *Standard Handbook of Hazardous Waste Treatment and Disposal.* U.S.A.: McGraw-Hill, Inc.

Glynn, W., Baker, C., Lore, A. & Quaglieri, A. (1987). *Mobile Waste Processing Systems and Treatment Technologies.* New Jersey: Noyes Data Corporation.

Hardie Iplex Pipeline Systems. *A Guide to Chemical Resistance of Thermoplastic and Elastromeric Materials.*

Hardie Iplex Pipeline Systems. *uPVC Pressure Technical Manual.* 1993.

Hooker, L. (1990). Danger Below. *Chemical Engineering Progress*, May, 52-60.

Kinsky, R. (1985). *Applied Fluid Mechanics*. Sydney: McGraw-Hill Book Company.

Lamont, P. Hardie Iplex Pipeline Systems. *uPVC Pressure Pipe Manual of Hydraulic Data and Formulae.*

Leva (1959). *Fluidisation*. New York: McGraw-Hill.

McKay, G. & Bino, M.J. (1990). Fixed Bed Adsorption for the Removal of Pollutants from Water. *Environmental Pollution, 66*, 33-53.

McKay, G. Bino, M.J., & Altamemi, A.R. (1985). The Adsorption of Various Pollutants from Aqueous Solutions onto Activated Carbon. *Water Resources, 19*, no4, 491-495.

Manahan, S.E. (1990). *Hazardous Waste, Chemicals, Toxicology and Treatment.* Michigan: Lewis Publishers.

Noll, K.E., Gounaris, V. & Hou W. (1992). *Adsorption Technology for Air and Water Pollution Control*. Michigan: Lewis Publishers Inc.

Pirbazari, M., Badriyha, B.N. & Miltner, R.J. (1991). G.A.C. Adsorber Design for Removal of Chlorinated Pesticides. *Journal of Environmental Engineering, 117*, no1 (Jan/Feb).

Randtke, S.J. & Snoeyink, V.L. (1983). Evaluating G.A.C. Adsorptive Capacity. *Journal AWWA, Research and Technology*, August, 406-413.

Renzo, D.J. (1978). *Unit Operations for Treatment of Hazardous Industrial Waste.* New Jersey: Noyes Data Corporation.

Riley, J.F. (1987). Unique Hazardous Material Spill Control Agents and Methods. *Proceedings of the 4th Technical Seminar on Chemical Spills, February 10-12, 1987*. Ansul Fire Protection, Marinette: Wisconsin.

Ruthven, D.M. (1984). *Principles of Adsorption and Adsorption Processes*. New York: John Wiley and Sons.

Slejko, F.L. (1985). *Adsorption Technology: A Step-by-Step Approach to Process Evaluation and Application*. New Jersey: Tall Oaks Publishing, Inc.

Stevenson, P. (1992). PCPs: Crunch Time for the Timber Industry. *Terra Nova*, June, 16-35.

Stevenson, P. (1992). The Scandal of the PCP Dumps. *Terra Nova*, 10-15.

Trantina, G.G. & Minnichelli, M.D. (1993). Design, Selecting Materials for Optimum Performance. *Plastics Engineering*, August, 23-26.

Unterberg, W., Davis, S.L., Meluold, R.W., Stephen F.J. & Bush, F.G. (1988). *How to Respond to Hazardous Chemical Spills*. New Jersey: Noyes Data Corporation.

Valencia, G. & Gloyna, E.F. (1972). On the Synthesis of Activated Carbon Column Design Data. *Technical Report EHE-72-11, CRWR 90*. U.S.A.: University of Texas.

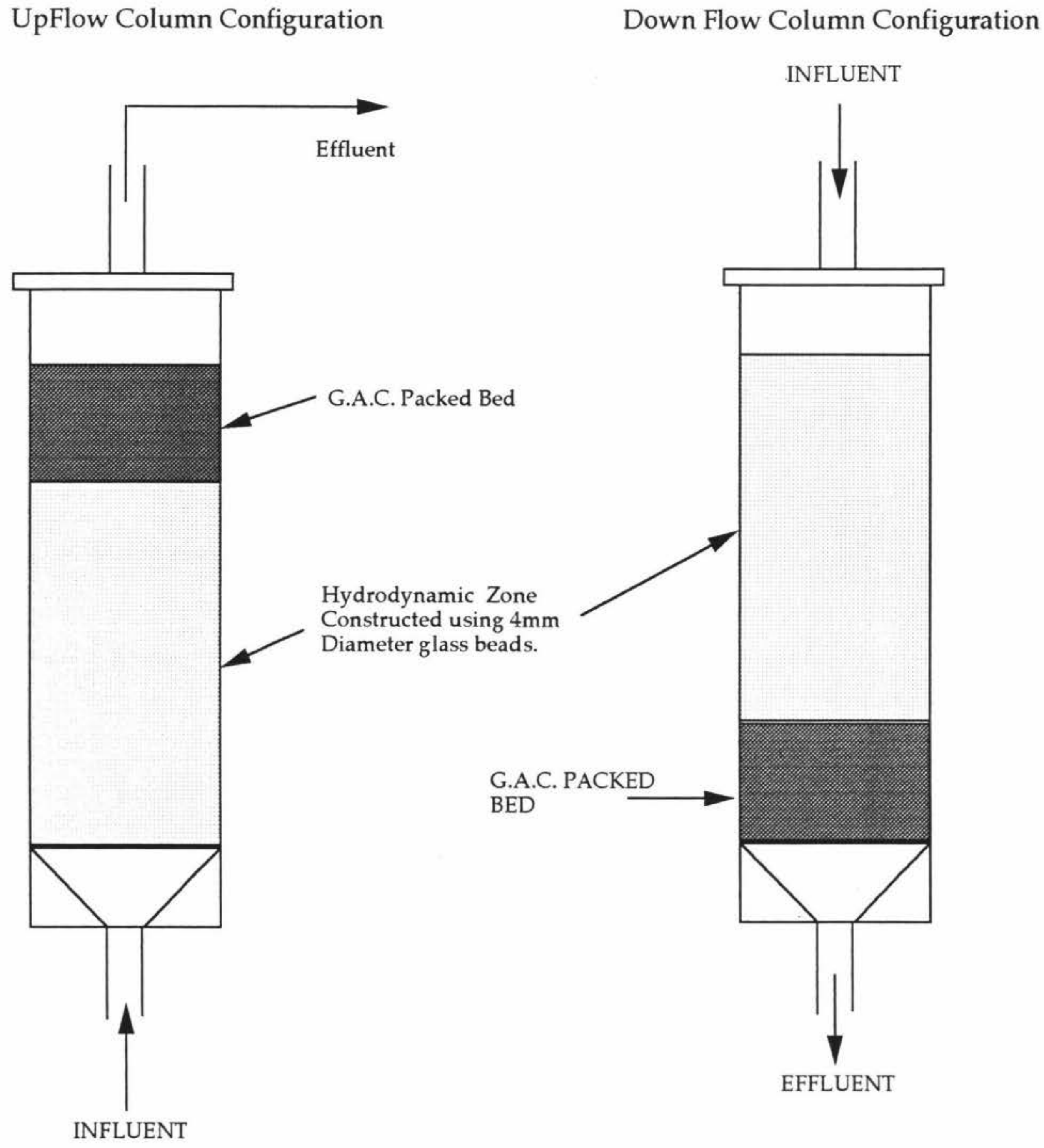
Vortmeyer, D. & Michael K. (1985). The Effect of Non-uniform Flow Distribution on Concentrations Profiles and Breakthrough Curves of Fixed Bed Adsorbers. *Chemical Engineering Science, 40*, no. 11, 2135-2138.

Weber, W.J., McGinley, P.M. & Katz L.E. (1991). Sorption Phenomena in Subsurface Systems: Concepts, Models and Effects on Containment Fate and Transport. Review Paper, *Water Resources, 25*, no5, 499-528.

Zajic, J.E. & Himmelman, W.A. (1978). *Highly Hazardous Materials Spills and Emergency Planning*. New York: M. Dekker.

APPENDIX

EXPERIMENTAL SET-UP
FOR SMALL SCALE COLUMN EXPERIMENTS



In both Upflow and Down Flow arrangements a positve displacement pump of variable stroke length was used. to pump the influent through the columns.

Column diameter = 4cm

G.A.C. Packed Bed Height = 3cm

APPENDIX A1

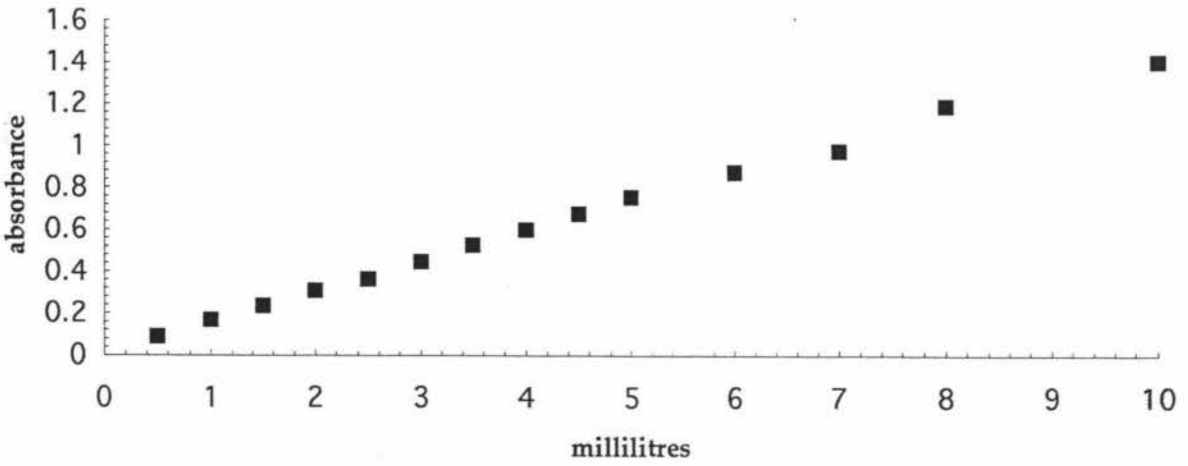
APPENDIX A2

2,4-D STANDARD CURVE CONSTRUCTION
(0-200 mg/L)

Table 1

	Sample Number		
	Absorbance units		
ml	1	2	Average
0.5	0.085	0.09	0.0875
1	0.165	0.17	0.1675
1.5	0.24	0.228	0.234
2	0.305	0.315	0.31
2.5	0.355	0.373	0.364
3	0.445	0.45	0.4475
3.5	0.55	0.5	0.525
4	0.6	0.6	0.6
4.5	0.67	0.68	0.675
5	0.75	0.76	0.755
6	0.87	0.88	0.875
7	0.92	1.03	0.975
8	1.18	1.2	1.19
10	1.41	1.4	1.405

U.V. SPECTROPHOTOMETER STANDARD CURVE FOR 2,4-D



APPENDIX A3

UPFLOW SMALL SCALE COLUMN EXPERIMENT			
Flow Rate=2.2 L/hr			
Weight of Carbon=19.9898g			
Initial Conc (mg/L)	200		
Time (seconds)	Absorbance	Effluent Conc	Dimensionless Conc
33	0.11	14.96	0.0748
57.5	0.09	12.24	0.0612
88.5	0.095	12.92	0.0646
112	0.1	13.6	0.068
137.5	0.1	13.6	0.068
166	0.102	13.872	0.06936
203	0.105	14.28	0.0714
234	0.11	14.96	0.0748
263	0.105	14.28	0.0714
293	0.103	14.008	0.07004
332	0.098	13.328	0.06664
360	0.095	12.92	0.0646
390	0.082	11.152	0.05576
422	0.082	11.152	0.05576
450	0.085	11.56	0.0578
477.5	0.086	11.696	0.05848
504	0.085	11.56	0.0578
538.5	0.085	11.56	0.0578
567.5	0.082	11.152	0.05576
600.5	0.085	11.56	0.0578
623.5	0.086	11.696	0.05848
647	0.085	11.56	0.0578
670	0.08	10.88	0.0544
708.5	0.086	11.696	0.05848
735.5	0.087	11.832	0.05916
762	0.09	12.24	0.0612
796	0.086	11.696	0.05848
826	0.09	12.24	0.0612
860.5	0.088	11.968	0.05984
890.5	0.09	12.24	0.0612
914.5	0.09	12.24	0.0612
937.5	0.086	11.696	0.05848
967.5	0.087	11.832	0.05916
985.5	0.09	12.24	0.0612
1016.5	0.091	12.376	0.06188
1045	0.091	12.376	0.06188
1064.5	0.091	12.376	0.06188
1095.5	0.092	12.512	0.06256
1120	0.093	12.648	0.06324
1159	0.094	12.784	0.06392

APPENDIX A3

1189.5	0.09	12.24	0.0612
1213.5	0.091	12.376	0.06188
1238	0.095	12.92	0.0646
1270.5	0.095	12.92	0.0646
Upflow Column Data			
Flowrate (L/hr)	2.2		
Amount of Carbon (g)	19.99		
Bed Height (cm)	3		
Column Diameter (cm)	4		
X-Sectional Area of column (cm2	12.57		
Volume of Bed (cm3)	37.71		
Volumetric Contat Time (s)	62.85		
Bulk Density (Dry) (g/cm3)	0.53		
Bed Porosity	0.47		
Velocity (cm/s)	0.10		
Mean Residence Time (L/V) (s)	29.53		

APPENDIX A4

DOWN FLOW SMALL SCALE COLUMN EXPERIMENT			
Flow rate=2.2 L/hr			
Weight of carbon=19.9977g			
Initial Conc=	0.151/1ml		
	.50/3ml		
Initial conc=	221		
Time (s)	Absorbance	Concentration(ppm)	Dimensionless Conc
20.5	0.11	14.96	0.067692308
57	0.102	13.87	0.062769231
87	0.108	14.69	0.066461538
112.5	0.1	13.60	0.061538462
136.5	0.11	14.96	0.067692308
162	0.102	13.87	0.062769231
190.5	0.1	13.60	0.061538462
211.5	0.104	14.14	0.064
242	0.103	14.01	0.063384615
262	0.105	14.28	0.064615385
288.5	0.111	15.10	0.068307692
313	0.114	15.50	0.070153846
338	0.112	15.23	0.068923077
362.6	0.12	16.32	0.073846154
388.5	0.115	15.64	0.070769231
415	0.118	16.05	0.072615385
448.5	0.12	16.32	0.073846154
468.5	0.12	16.32	0.073846154
487	0.12	16.32	0.073846154
506.5	0.121	16.46	0.074461538
526	0.121	16.46	0.074461538
549	0.125	17.00	0.076923077
570	0.126	17.14	0.077538462
591	0.13	17.68	0.08
616.5	0.13	17.68	0.08
639	0.131	17.82	0.080615385
661.5	0.13	17.68	0.08
686	0.13	17.68	0.08
706.5	0.132	17.95	0.081230769
737.5	0.135	18.36	0.083076923
759.5	0.135	18.36	0.083076923
780.5	0.13	17.68	0.08
803.5	0.135	18.36	0.083076923
824.5	0.136	18.50	0.083692308
846.5	0.136	18.50	0.083692308
868	0.137	18.63	0.084307692
888	0.138	18.77	0.084923077
908.5	0.139	18.90	0.085538462
927.5	0.14	19.04	0.086153846
948	0.142	19.31	0.087384615

968.5	0.14	19.04	0.086153846
989.5	0.141	19.18	0.086769231
1012.5	0.142	19.31	0.087384615
1026.5	0.142	19.31	0.087384615
1050	0.143	19.45	0.088
1069.5	0.149	20.26	0.091692308
1093.5	0.144	19.58	0.088615385
1116	0.148	20.13	0.091076923
1142	0.149	20.26	0.091692308
1169	0.15	20.40	0.092307692
1190.5	0.15	20.40	0.092307692
1219	0.151	20.54	0.092923077
1240.5	0.155	21.08	0.095384615
1265.5	0.155	21.08	0.095384615
1287.5	0.153	20.81	0.094153846
1316	0.152	20.67	0.093538462
1337.5	0.155	21.08	0.095384615
1357	0.155	21.08	0.095384615

APPENDIX A5

Minimum Fluidisation Velocity Calculation for G.A.C.

Minimum fluidisation velocity is determined using the following equation:-

$$U_{mf} = 0.0055 \frac{e^3{}_{mf}}{1 - e_{mf}} \frac{d^2(\rho_s - \rho)g}{\mu}$$

where:- e_{mf} = bed voidage

d = average diametre of granualr activated carbon particles

g = gravitaional constant

μ = fluid viscosity

ρ = fluid density

ρ_S = density of granualr activated carbon particle.

The follwing values were used for the above 0.47, $1\text{x}10^{-3}$ m^2, 9.81 m/s^2, 1002 μPas, 1000 kg/m^3, 2200 kg/m^3.

This gives a minimum fluidisation velocity of 0.759 m/min. Normal practice to limit upflow velocity to 80% of Umf, therfore max upflow velocity = 0.61m/min.

Pressure Drop Calculations for Fixed Beds of Granular Solids.

For the flow of a single compressible fluid through an incompressible bed of granular solids, the pressure drop or the flow characteristics can be predicted from the correlation given by Leva, (Fluidisation, Mcraw-Hill, New York, 1959). This correlation being:-

$$\Delta p = \frac{2 \mathrm{fm}\, G^2 L (1-\varepsilon)^{3-n}}{\mathrm{Dp}\, g_c \rho\, \phi_s^{3-n}\, \varepsilon^3}$$

where

n = exponent, a function o the modiied Reynolds number N'_{Re} given in figure 1 overleaf.

fm = friction factor, a function of N'_{Re}, given in figure 1 overleaf.

ϕ_S = shape factor of the solid (quotient of the area of a sphere equivalent to the volume of the particle divided by the actual surface of the particle (dimensionless)

The modified Reynolds number N'_{Re} is defined as:

$$N'_{Re} = \frac{D_p G}{\mu}$$

In laminar flow ($N'_{Re} < 10$),

$$\mathrm{fm} = 100 \,/\, N'_{Re}$$

Granular activated carbon was assumed to be near spherical and a shape factor of 0.95 was used in the calculation.

APPENDIX A6

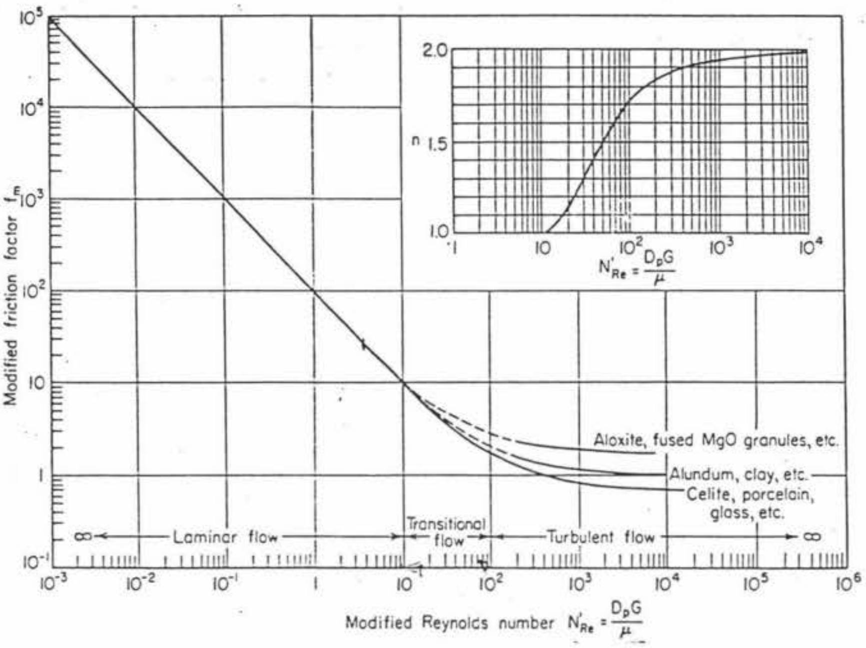
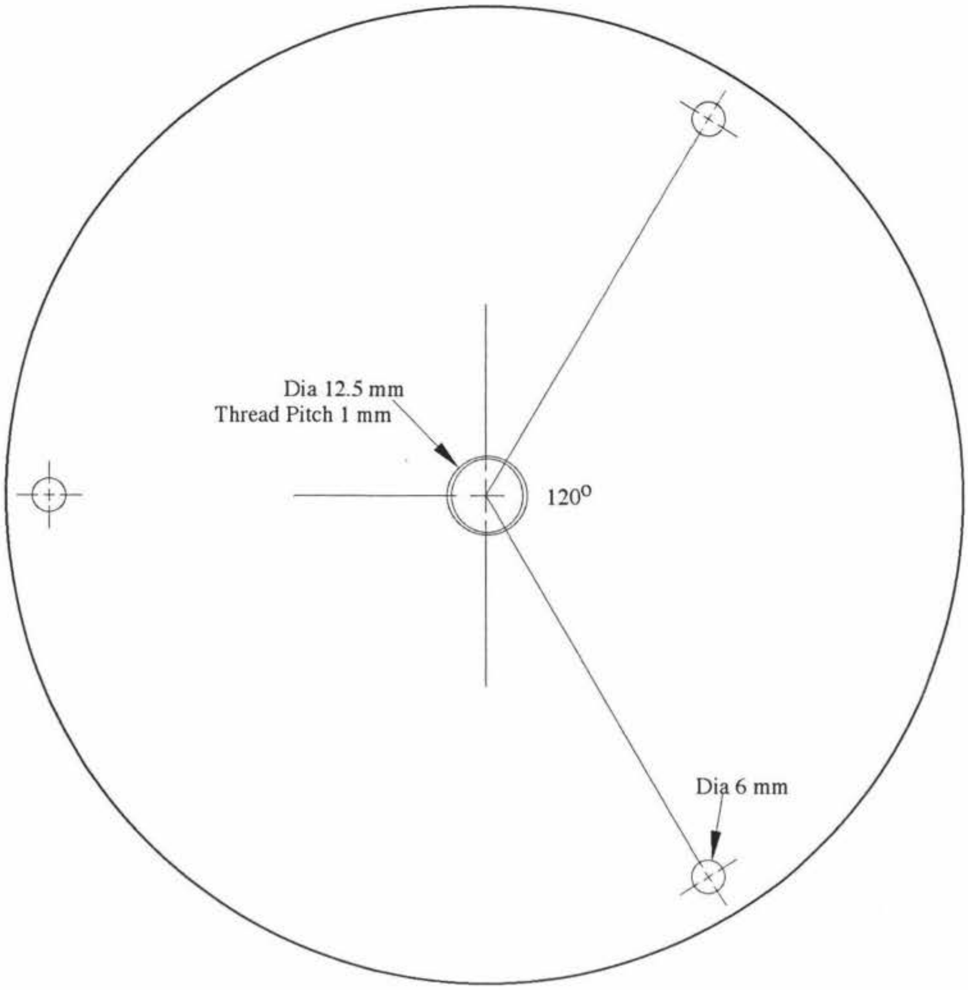
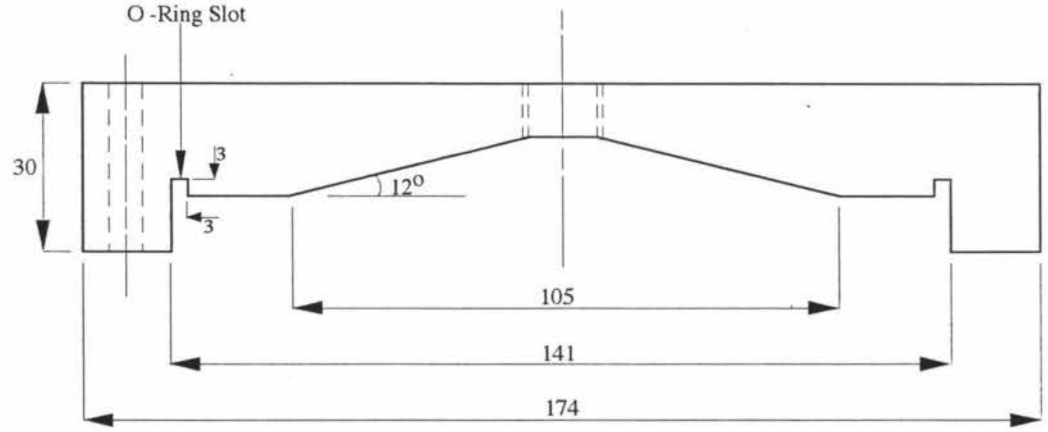


Figure 1 Friction Factor for Beds of Solids

(Leva, Fluidisation, McGraw-Hill, New York, 1959, p-49)



Plan View



Front Elevation

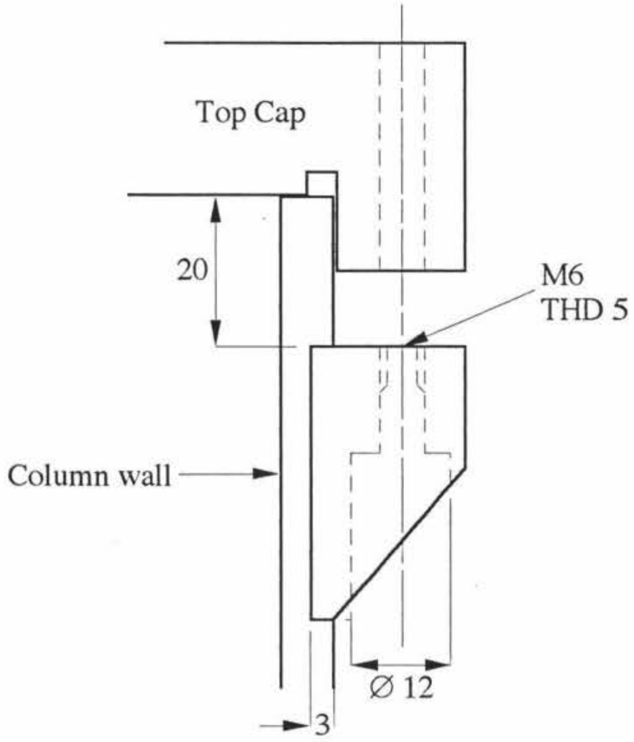
APPENDIX B1

SCALE: 1/1.333 | Material: P.V.C | Drwg No: AC / 1

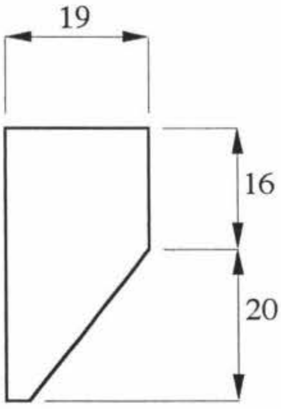
ALL DIMENSIONS IN MILLIMETRES

TITLE: REMOVABLE ADSORPTION COLUMN CAP

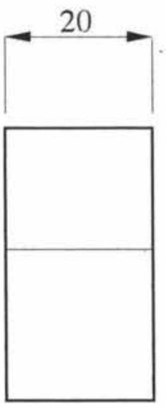
DRAWN BY: M.W. Hynes | Date: 15/10/92



Note: Three required per column.



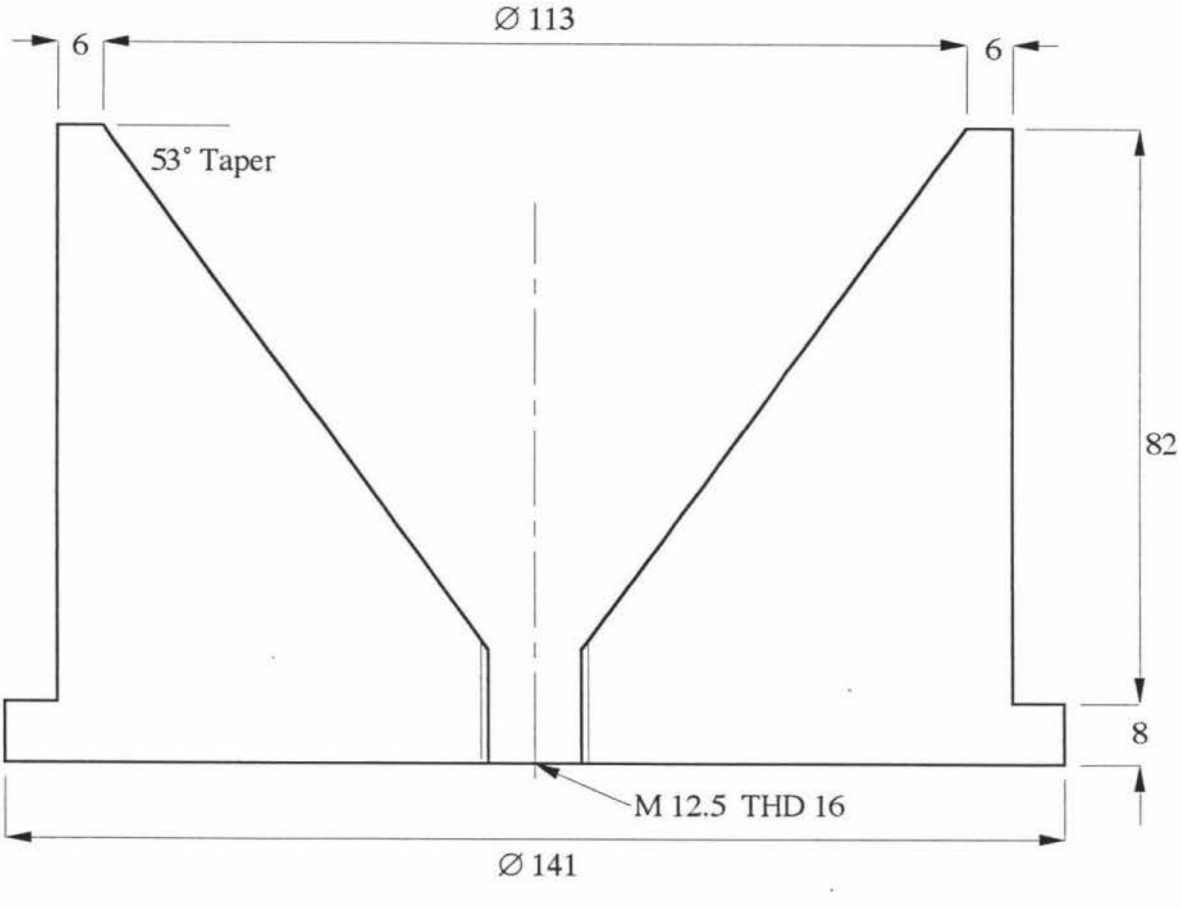
Front Elevation



R.H. End Elevation

APPENDIX B2

	SCALE 1:1	Material P.V.C	Drwg No: AC / 2
TITLE: TOP CAP SECUREING SYSTEM	ALL DIMENSIONS IN MILLIMETRES		
	DRAWN BY: M.W. Hynes		Date: 21/10/92

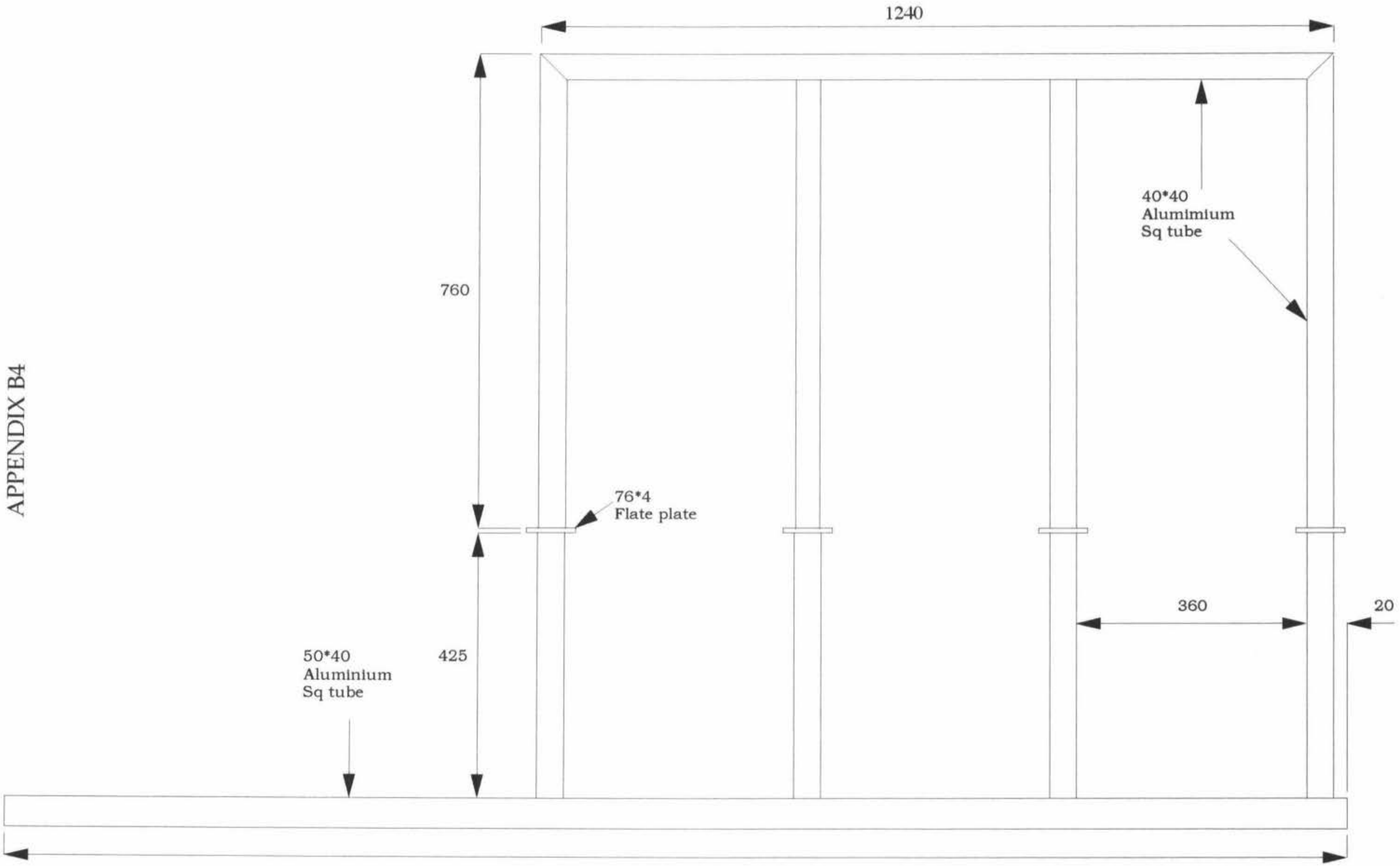


Notes: The above is top be made from 3
sections of 30 mm thick P.V.C
sheet bonded together using
P.V.C solvent.

APPENDIX B3

SCALE 1:1
Material P.V.C
Drwg No: AC / 3
ALL DIMENSIONS IN MILLIMETRES
TITLE: TAPERED END SECTION
DRAWN BY: M.W. Hynes
Date: 21/10/92

APPENDIX B4



TITLE: PORTABLE ADSORPTION UNIT SCHEMATIC

DRAWN BY: M.W. Hynes

Not to Scale

DATE:- 9/10/92

APPENDIX C1

INSTRUCTION
AND
SERVICE MANUAL

Wet Vacuum Cleaner

WB Series

TSURUMI MANUFACTURING CO., LTD.

4. Earth Leakage Circuit Breaker

Use an earth leakage circuit breaker to prevent electrical accident.

OPERATION

1. Connect the unit to a single-phase AC power outlet.

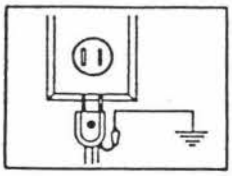


Fig 1-1

2. Connect the grounding wire with the "E" marked grounding terminal on the head cover.

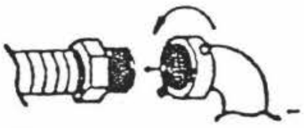
3. Trial Operation (Dry operation)
   After connecting electrical circuit, operate the unit under no-load conditions to ensure that the pump will rotate.(Max. 10 minutes)
   A humming sounds during this operation - this is a blowing sound by the impeller.

4. Priming Water
   Remove the plug (P/NO. 9) and fill the tank with at least four(4) litters of clear water. If priming water is sufficient, it may affect vacuum and suction power.
   Do not pour water from the plug on the head cover (P/NO. 25) - this is for the impeller-lock release purpose.

5. Connect hoses to outlet and inlet respectively.
   use the hose retainer at the delivery hose end. This retainer can be fixed by a rope as it has two holes.
   Use several attachment for suction, depending on jobs.
   It is easy to connect hoses without any tools.

6. After use, run the unit about one(1) minute with clean water, then clean the strainer(P/NO. 13).

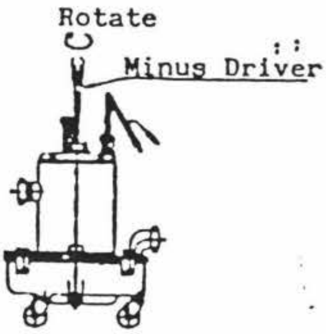
7. Remove the drain plug(P/NO. 16), drain the water completely, and dry.



CAUTIONS

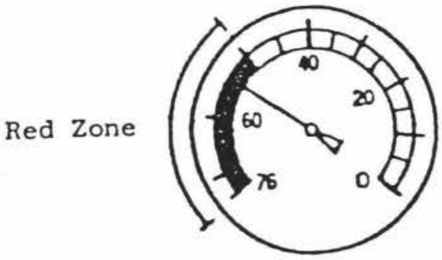
When the unit do not start due to "Impeller lock" after the snap switch is "ON", switch "OFF" first and rotate the shaft by minus screw driver by a hand.

If not rotated manually, it is likely that the impeller has been locked due to obstruction.
Disassembly and remove obstruction.



When the suction power dropped suddenly :

1. When trash gauge points the red coloured zone, the strainer, suction head or inside suction hose is obstructed.
   Clean the strainer, inside the suction hose and/or the head.
2. When the the points has not reached to the red zone, check the connection of hoses and pipes for air leakage.
   Suction power is also dropped if water in the unit is insufficient.
   Refill with clean water.
   Water in the unit goes out little by little through the dicharge hose.
   When the unit handles water and air, necessary volume of water remains always full.
   When the unit handles air only, clean water should be refilled hourly.



Avoid the unit operating in vacuum for a long time (Cooling is not sufficient under this operation)
Please limit this operation to 30 minutes.

The motor stops automatically in this case to prevent the motor from burn-out. When the motor protector sensed overheating, the protector senses over-current to protect the motor from burn-out too.

Circle thermal protector
The motor protector is actuated against excessive temperature rise in motor due to overloads, and will be automatically reset to start the motor again when back to normal temperature.
Make sure it is switched "OFF" for services.
Meantime, frequent actuation of the protector may cause motor burn-out at last. Shoot and correct the trouble souces.

Do not operate without trash strainer.
Foreign matters may go into the unit, and obstruct the impeller.

Fasten the hose connections tightly to avoid air leakage.
loose connection may cause insufficient suction power.

Do not handle pumping media more than 40°C.
The motor protector actuates frequently.

This unit should not be used for flammable or explosive liquids.

Being non-submersible type, do not submerge the unit.

Ensure the cable end and the snap switch kept off water, since it may cause electricity leakage. Operators are suggested to wear rubber gloves and boots.

Make sure to run the unit about one(1) minute with clean water, clean the strainer, and drain the water completely.

MAINTENANCE AND INSPECTION

1. Lubricant Oil

Inspection cycle —— every 1,000 hours
Replacement cycle —— every 2,000 hours

HOW TO INSPECT ;

1. Remove 3 wing bolts off the tank.
2. Remove the Guide Casing.
3. Remove the Pump Casing.
4. Remove Impeller nut (M10 Hex. nut), pull Impeller out.
5. Remove Oil plug (use Hex. spanner)
6. Lay the pump, take a little volume of oil, and check if the oil contain water. When the oil is coloured yellowish gray, replace it.

Oil Capacity : Turbine Oil #32 200cc

NOTE: Replace oil plug packing if worn.

Please assemble the unit after changing oil in the reverse order aginst above.

NOTE: Make sure that the port cylinder does not touch the impeller when pump casing is fixed back.

2. Electrical check (Megger Test)

- Inspection - every 500 hours operation.
Check insulation resistance of all phases against Earth lead wire(Green).
If it reads less than 20 M. Ohm, the unit should be serviced.

3. After operating for a long time, close the suction inlet tentatively, and read the vacuum gauge.
When the graduation reads less than "30", it indicates that servicing the unit is necessary.

SPECIFICATION

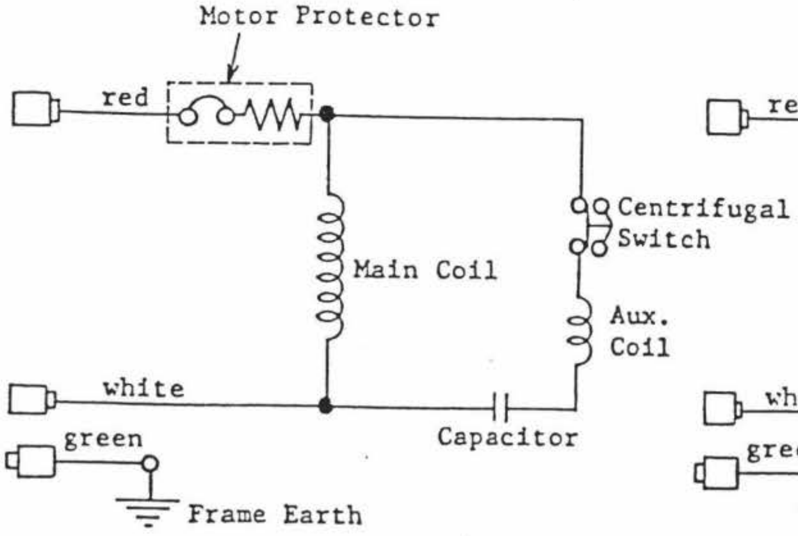
TSURUMI PUMP

Model	WB-5
Bore Size	25 mm (1")
Motor Output	550W, 2Pole
Max. Air volume	260 NL/min (50Hz), 320 NL/min (60Hz)
Max. Vacuum	600 mmHg
Max. Disc. Capacity	45 L/min (50Hz), 50 L/min (60Hz)
Max. Disc. Head	4.0 m (50Hz), 5.0 m (60Hz)
Cabtyre Cable	VCT 3c x 1.25mm2 x 5 m
Power Source	Single-phase, 50Hz/60Hz

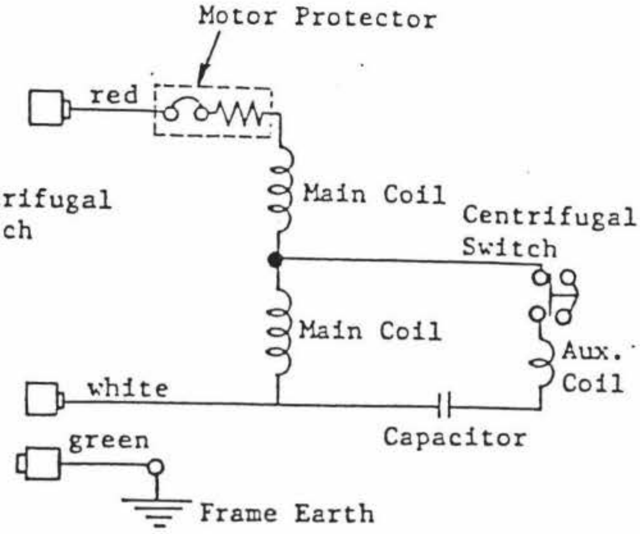
*Specifications are subject to change without notice.

WIRING CIRCUIT

110 volts



200 - 240 volts



TROUBLE SHOOTING

FAULT	PROBABLE CAUSE	POSSIBLE REMEDY
Fails to start	1. No electricity	1. Correct and/or on power source
	2. Break in or poor connection	2. Repair and/or make correct connection
	3. Something is lodged in impeller	3. Remove whatever is blocking the impeller
Starts but suction power is insufficient	1. Priming water is insufficient	1. Top up
	2. Break in suction Hose or pipe	2. Repair or change
	3. Loose connection through suction joints	3. Fasten joints tightly
	4. Impeller and others worn	4. Change
Pump stops during running	1. No electricity (Break in or poor connection)	1. Correct and/or turn on power source. Repair and/or make correct connection.
	2. Something is lodged in impeller	2. Remove whatever is blocking the impeller.
Pump is tripping	1. The trash strainer is choked (Meter indicates red zone)	1. Clean the strainer
	2. Pumping is insufficient due to lower volume of water in disc. chamber.	2. Fill up with clear water
	3. Break in suction hose	3. Repair or change
	4. Loose connection through joints	4. Fasten joints tightly

APPENDIX C2

TURBINE INSTALLATION GUIDELINES

Flow measurement accuracy using a Turbine Meter is dependent upon proper application, installation and use. To obtain optimum performance using a GPI Turbine Meter, the following guidelines are provided:

GENERAL:

Before using the meter in your system, be sure of the following:

(1) The working flow rate is within the limits of the meter;

(2) The fluid is compatible with the meter construction materials;

(3) The maximum working pressure of the system does not exceed the maximum pressure rating of the meter;

(4) The meter is not installed in close proximity to any electrically "noisy" enviroments.

FLOW DIRECTION:

All GPI turbine meters are designed to measure flow in one (1) direction only. This can easily be identified by a flow direction arrow that is cast/molded into the turbine housing outlet fitting.

GPI turbine meters may be installed either horizontally or vertically, but should be calibrated or verfied in the position in which it will be used. Meters are calibrated in the horizontal position at the factory.

FOREIGN MATERIALS:

Fluid characteristic parameters which can affect the meter's performance include: Foreign material, temperature, pressure, viscosity, wear and corrosion.

To prevent foreign material from clogging the rotor, it is recommended that the following screen/filter be installed upstream of the meter:

0.3-3.0 GPM (1-10 LPM) — 25 micron (.001 Dia.)
3.0-30 GPM (10-100 LPM) — 350 micron (.015 Dia.)
30-300 GPM (100-1000 LPM)— 350 micron (.015 Dia.)

If foreign material is allowed to enter the meter, metering errors may result. Re-calibration may not solve the problem if debris is coated on the rotor and not allowing it to turn freely. The rotor should be checked to verify that it is free to rotate.

SYSTEM PRESSURE REQUIREMENTS:

Vapor pockets in the flow stream, referred to as cavitation, can cause the turbine meter to give inaccurate readings.

If cavitation occurs upstream of the meter, metering errors will also occur. For this reason, do not place a flow control valve on the upstream side of the meter, especially if measuring fuels, oils, solvents and other fluids with low vapor pressures.

Cavitation can usually be eliminated by placing a flow control valve on the downstream side of the meter, at the proper distance from the turbine, to build-up back-pressure in the system. See Meter Installation section for proper downstream distance.

A typical back-pressure of 5-50 PSI and proper installation of the meter will prevent cavitation. The lower the flow rate, the lower the back pressure required.

⚠ CAUTION

The most common cause of inaccurate meter readings is improper installation.

Proper care must be taken to correctly install turbine meters for accurate measurements.

METER INSTALLATION:

Proper installation of the meter in the piping system is required t achieve maximum measurement accuracy. The velocity profile o the flow stream entering the meter must be uniform thoughout th cross-section of the pipe. If a non-uniform velocity profile exists or if other flow disturbances, such as pulsation or swirl, are prese in the flow stream, the performance of the meter may be affected It is recommended that the meter be installed with straight pipe lengths of at least twenty times the meter bore diameter (20d) (d=meter bore diameter.) upstream and at least five times the met bore diameter (5d) downstream. *See Figure 1*. This will minimi the non-uniform velocity and/or swirling that is caused by elbow or valves in the system upstream of the meter. Flow straightenin vanes, placed upstream from the meter, shorten the upstream pip length requirement to 10d and will enhance meter accuracy.

SPECIFICATIONS

0.3 to 3 GPM Flow Range (1-10 LPM)

- 1" NPT (ISO) female inlet & outlet threads.
- 1/4" ID fluid passage.
- 2 PSIG pressure drop (H_2O) at 3 GPM.

3 to 30 GPM Flow Range (10-100 LPM)

- 1" NPT (ISO) female inlet and outlet threads.
- 1" ID fluid passage.
- 1 PSIG pressure drop (H_20) at 30 GPM.

30 to 300 GPM Flow Range (100-1000 LPM)

- 2" NPT (ISO) female inlet and outlet threads.
- 2" ID fluid passage.
- 7 PSIG pressure drop (H_2O) at 300 GPM.

All stated flow ranges are for non-viscous fluids. Consult the factory for information on viscous fluids.

Maximum Turbine Working Pressure

- Aluminum = 300 PSI (20.7 bar)
- 316 Stainless Steel = 800 PSI (55.2 bar)
- Nylon = 150 PSI (10.3 bar)

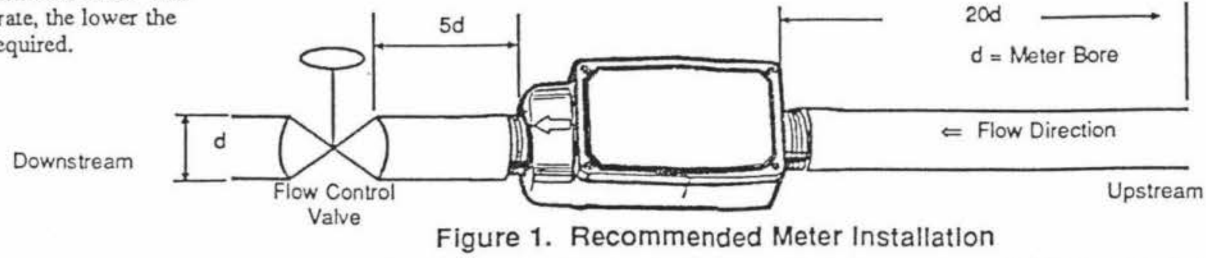


Figure 1. Recommended Meter Installation

CALIBRATION:

When the temperature of the fluid changes or differs from the calibrating temperature, the physical properties of the metered liquid can change, affecting the accuracy of the meter. Any fluid property changes, including viscosity, density, specific gravity and vapor pressure, will affect meter accuracy. Accuracy changes can be avoided by *calibrating* the meter with any fluid property change, including working flow rate.

When calibrating the meter, it is important that an accurate fluid volume measurement sample be used. This will require a calibrated container or a meter prover. It is recommended that the meter calibration be checked on a regular basis. (Low cost Calibration Containers are available from GPI.)

K-FACTOR

A K-factor is the number of pulses generated by the spinning turbine to equal one unit.

In GPI's case, this unit equals one gallon. This K-factor is taken at one particular point or flow rate.

GPI provides a K-factor on each meter at a given flow rate. Refer to the K-factor charts below for general K factor vs. flow rte information (non-viscous fluids).

MAINTENANCE

The GPI turbine requires very little maintenance. Always flush the turbine after use to ensure that deposits don't dry inside housing. Use the chemical manufacturer's suggested cleaning agent. **Never blow high pressure air through the turbine assembly.**

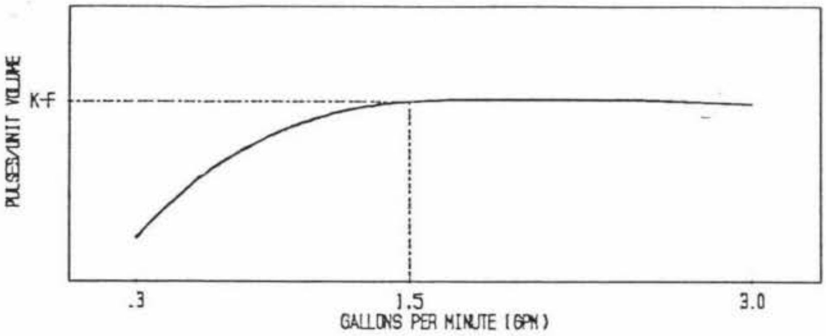
The rotor in the turbine assembly must turn freely. If the rotor is restricted due to foreign objects, apply penetrating lubricant directly on the rotor, shaft and bearings. Then remove the deposits taking care not to damage the rotor and supports.

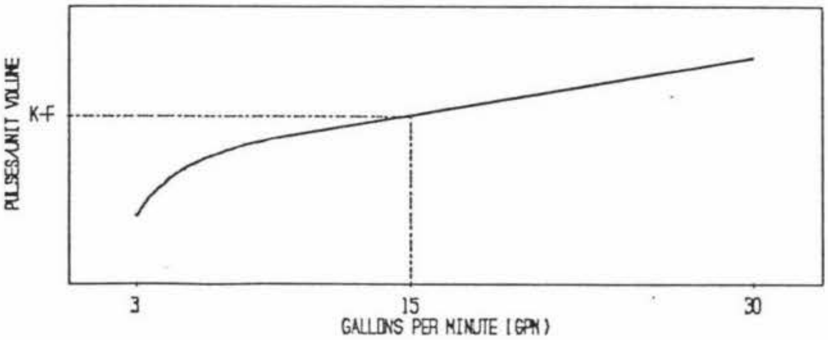
WARRANTY

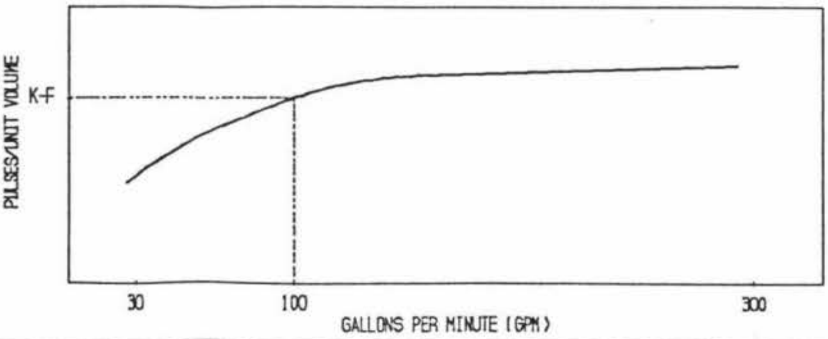
The GPI Turbine is warranted for a period of 1 year from date of purchase against defects in material and workmanship. This warranty will not apply if product is subjected to misuse, neglect, accident, improper installation, or is altered or repaired by unauthorized persons.

GPI's sole obligation under this warranty shall be limited to (at its option) repair or replacement and shall not be liable for any indirect or consequential damages or loss arising from any cause whatsoever.

This warranty is given in lieu of any other warranty expressed or implied. This warranty gives you specific rights and you may have other rights which vary from state to state.







1711 S. Longfellow
Wichita, KS 67207
316-686-7361
Fax No. 316-686-6746

GREAT PLAINS INDUSTRIES, INC.

990, GREAT PLAINS INDUSTRIES, INC., Wichita, KS. Printed in the U.S.A. 10/90.

APPENDIX D1: COLUMN EVALUATION DATA

Portable Adsoption Unit Column Evaluation Data			
Trial 1			
Influent concentration (mg/L)	102		
Flowrate (L/min)	3		
Time	Adsorbance	Effluent Conc (mg/L)	C/Co
294			
306	0.001	0.138	0.00135294
318	0.002	0.276	0.00270588
330	0.003	0.414	0.00405882
342	0.004	0.552	0.00541176
354	0.006	0.828	0.00811765
366	0.009	1.242	0.01217647
396	0.011	1.518	0.01488235
426	0.018	2.484	0.02435294
456	0.027	3.726	0.03652941
486	0.037	5.106	0.05005882
516	0.055	7.59	0.07441176
546	0.072	9.936	0.09741176
Trial 2			
Influent Concentration (mg/L)	199		
Flowrate (L/min)	1.5		
Time	Adsorbance	Effluent conc (mg/L)	C/Co
390	0.002	0.276	0.00138693
402	0.003	0.414	0.0020804
414	0.003	0.414	0.0020804
426	0.006	0.828	0.0041608
438	0.008	1.104	0.00554774
452	0.01	1.38	0.00693467
464	0.011	1.518	0.00762814
476	0.014	1.932	0.00970854
506	0.02	2.76	0.01386935
536	0.027	3.726	0.01872362
566	0.034	4.692	0.02357789
596	0.046	6.348	0.0318995
626	0.062	8.556	0.04299497
656	0.078	10.764	0.05409045
686	0.103	14.214	0.07142714
716	0.128	17.664	0.08876382
746	0.147	20.286	0.1019397

APPENDIX D1: COLUMN EVALUATION DATA

Portable Adsoption Unit Column Evaluation Data			
Trial 3			
Influent concentration (mg/L)	303		
Flowrate (L/min)	2		
Time	Adsorbance	Effluent Conc (mg/L)	C/Co
210	0.004	0.552	0.00182178
222	0.006	0.828	0.00273267
234	0.008	1.104	0.00364356
246	0.009	1.242	0.00409901
258	0.012	1.656	0.00546535
270	0.015	2.07	0.00683168
282	0.024	3.312	0.01093069
312	0.036	4.968	0.01639604
342	0.057	7.866	0.0259604
372	0.087	12.006	0.03962376
402	0.148	20.424	0.06740594
432	0.21	28.98	0.09564356
Trial 4			
Influent concentration (mg/L)	398		
Flowrate (L/min)	3		
Time	Adsorbance	Effluent Conc (mg/L)	C/Co
126	0.007	0.966	0.00242714
138	0.013	1.794	0.00450754
150	0.022	3.036	0.00762814
162	0.035	4.83	0.01213568
192	0.07	9.66	0.02427136
222	0.06	8.28	0.02080402
252	0.275	37.95	0.09535176