AN INVESTIGATION OF UV DISINFECTION OF FARM DAIRY WASTEWATER

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AN INVESTIGATION OF UV DISINFECTION OF FARM DAIRY WASTEWATER

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ABSTRACT

The development of New Zealand dairy farming industry is characterised by a trend towards more intensified farming operations (larger herd sizes). This is placing greater demand for freshwater uses and effluent discharges. To comply with the microbiological standards, wastewater from farm dairies may be disinfected. Ultraviolet irradiation provides one of the best alternatives to traditional disinfection technologies.

With the development of technology and the awareness of the hazards of disinfection by-products, UV irradiation is increasingly used successfully world-wide for both drinking and wastewater disinfection. Due to the lack of data on the nature of farm dairy wastewater, no information was available on the application of UV to dairy effluents.

Wastewater samples were collected from farm dairies and analysed for characteristics relative to UV disinfection. Suspended solids (SS) contributed to nearly half the COD and 80% of the turbidity of the pond treated wastewater. Colloidal material in the 0.22 to 1.0 micron range constituted nearly 18% of the COD and 15% of the turbidity of the raw pond effluent.

Farm dairy wastewater quality changed with season. With the commencing of milking season, wastewater suspended solids, COD, and turbidity increased sharply due to the increased influent loading. However, wastewater BOD was similar over the monitoring period. With the exception of temperature and pH, wastewater quality parameters monitored showed great variation among different sites. These variations may be due to the difference in farm operation and management.

Pond treated farm dairy wastewater could not be directly disinfected by UV due to the high suspended solids (317 mg/l), COD (809 mg/l) concentration, high turbidity (450 NTU) and low UV transmittance (0%/cm). Filtration through 1.2, 0.45, and 0.22 micron filter removed all suspended solids and most of the turbidity, but UV transmittance

remained lower than 1%/cm. Alum coagulation followed by 0.45 micron filtration removed most of the colloidal material and improved UV transmittance up to 29%/cm. The dissolved organic matter was successfully removed by 0.5 g/l activated carbon (AC) adsorption following aluminium sulphate coagulation treatment. To reach 60%/cm UV transmittance, AC dose of 5 g/l was required for raw pond effluent. Bark and zeolite treatment removed ammonium from farm dairy wastewater. Bark and zeolite treatment did not greatly improve raw pond effluent UV transmittance at 254 nm. Ultracentrifugation at 10,500 g for one hour did not significantly improve UV transmission through alum coagulated farm dairy wastewater. Hydrogen peroxide was found not helpful in improving UV penetration. Strong correlation existed between UV absorbance and COD concentration. UV absorbance may be used as a parameter for estimating wastewater COD level.

Keywords: Farm dairy wastewater, ultraviolet (UV), disinfection, dilution, filtration, alum coagulation, hydrogen peroxide, activated carbon, UV transmittance.

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CHAPTER ONE
INTRODUCTION

The Expanding New Zealand Dairy Farming Industry

The dairy industry has recently undergone such sustained and rapid growth that its contribution to New Zealand's wealth has been growing more rapidly than GDP (NZDB, 1997). In addressing the Forestry Research Institute Conference in Rotorua, Board Chairman Sir Dryden Spring told the audience: "The dairy industry is New Zealand's largest export earner with sales of $3.7 billion in 1996, which accounted for 17.1 percent of this country's merchandise trade". To the year ended 31 May 1997, the turnover of the Board reached record-breaking value of $6 billion. These figures showed that over the last five years, sales volume had grown by 16 percent, while value had increased by 29 percent (NZDB, 1997). The Board's share of the world export dairy trade is up to 28 percent, compared to 19 percent seven years ago (NZDB, 1996).

Though the total number of dairy farms in New Zealand has declined from 18,540 farms in 1974/75 to 14736 farms in 1995/96 (LIC, 1996), the average herd size is increasing from 112 cows in 1974/75 to 208 cows in 1996/97 (**Figure 1-1**) (LIC, 1997). This has resulted in an overall trend of increasing total number of dairy cows, from 2,079,886 cows in 1974/75 to 3,064,523 cows in 1996/97 (LIC, 1997).

The Impacts of Dairy Farming on Water Resources

There has been a trend towards more intensified dairy farming operations with higher stocking rates. The average stocking rate has increased from 2.1 cow/ha in 1981/82 to 2.5 cow/ha in 1996/97 (LIC, 1997). This is placing greater demand on water resources in New Zealand. On an average day the dairy farming industry uses a total of 153 million litres of water, at 50 litres per cow per day (Heatley, 1995) for washdown purpose and produces the same amount of effluent. The increase in fresh

water use and wastewater production due to the growth in dairy cow numbers and the intensification of dairy farming operation may not only aggravate fresh water shortage but also intensify environmental pollution.

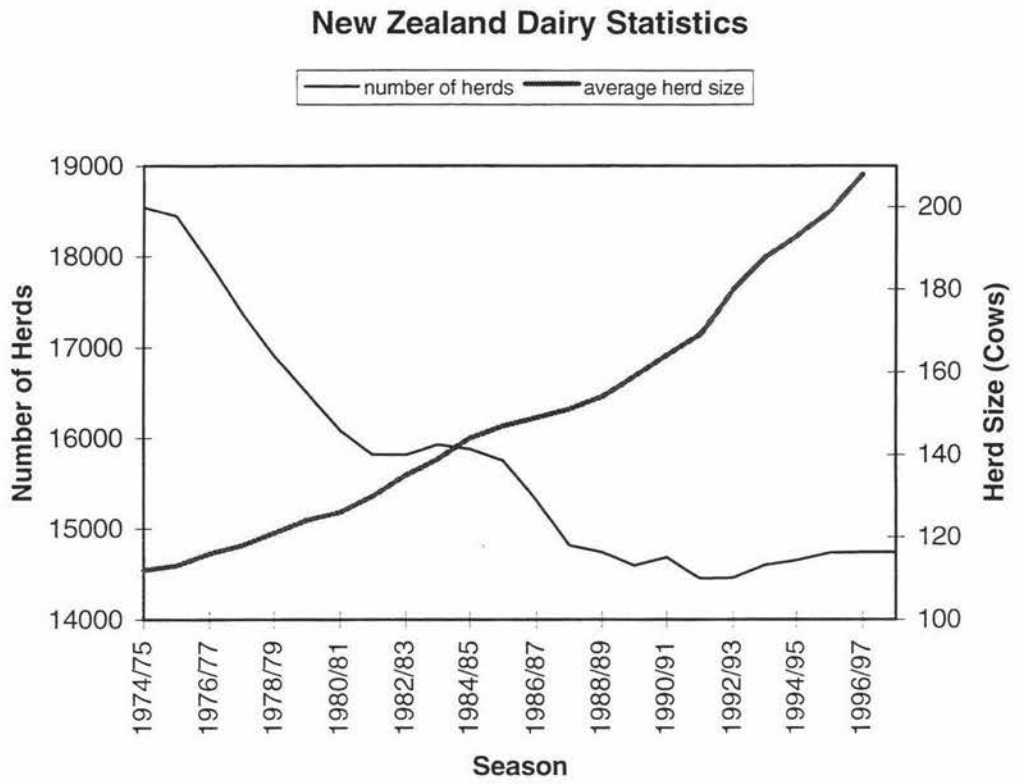

Figure 1-1 Trends in herd number and size in New Zealand (LIC, 1997)

The Need for Farm Dairy Wastewater Disinfection

In addition to raised levels of nutrients (N and P), suspended solids, colour and oxygen demand, farm dairy wastewater contains high concentrations of microbial contaminants. Due to the climate and soil limitations, land application of farm dairy effluent is only applicable to some areas in some seasons. Considerable amounts of dairy wastewater are still discharged into natural waterways (Bolan *et al.*, 1996; Sukias *et al.*, 1996). Because of the poor performance of pond systems in reducing microbial density in the farm dairy wastewater, dilution of over 2700-fold was required to reach the bacterial standard for recreational bathing (Hickey *et al.*,

1989a). This required dilution factor is usually not available due to the competitive use for the water resources. On the other hand, effluent disinfection before discharging into waterways to meet the drinking and contact recreation standards of the receiving waters may provide better solution to the problem.

Ultraviolet Radiation for Farm Dairy Wastewater Disinfection

Due to the high organic matter content in pond treated farm dairy wastewater, traditional disinfection technologies, such as chlorination and ozonation, may not be successfully employed due to the potential problems. Because of the increasing awareness of the effluent toxicity and safety problems associated with chlorination, especially the production of dangerous disinfection byproducts after chlorination, ultraviolet irradiation has become the most common alternative to chlorination for wastewater disinfection in North America (Bierck, *et al.*, 1996). Because the COD level was usually less than 40 mg/l in domestic wastewater (Stover *et al.*, 1986a), and higher than 400 mg/l in pond treated farm dairy wastewater (884 mg/l in Mason, 1994; 837 mg/l in Flowerday, 1997; and 615 mg/l in Bolan *et al.*, 1996), the ozone dose required for farm dairy wastewater disinfection could be predicted by Stover *et al.* (1986) as more than 10 times higher than that for domestic wastewater disinfection. This may increase the cost of ozonation to a prohibitive level. On the other hand, ultraviolet (UV) radiation has proven to be effective and economical for domestic wastewater disinfection (Bierck, *et al.*, 1996). Bierck *et al.* (1996) reported over 1 000 wastewater treatment plants in North America have chosen UV irradiation for wastewater disinfection. One manufacturer reported in 1997 that over 1 400 UV disinfection systems from the company were in operation around the world (Trojan Technologies Inc., 1997). However, the application of UV disinfection has not been extended to dairy shed wastewater. A preliminary study by Flowerday (1997) found that disinfection of diary shed wastewater by UV could be problematic due to the high concentrations of suspended solids, turbidity and dissolved organic materials. However, the nature of these materials was not characterised and the pretreatment used was limited to some physical ones. Further research is required on

the UV disinfection of farm dairy wastewater to investigate the nature of the material and techniques for the pretreatment.

CHAPTER TWO
LITERATURE REVIEW

2.0 INTRODUCTION

Starting from the historical development, this chapter reviewes the literature on the research and application of UV disinfection technologies. These include the spectra and mechanism of UV disinfection, factors affecting UV disinfection, design and operational considerations of UV disinfection systems. The last section outlines the objectives of this study

2.1 HISTORICAL DEVELOPMENT

The germicidal effect of UV radiation in sunlight was first discovered by Downes and Blunt in 1877 (Downes *et al.*, 1877), and in 1901 Hewitt developed a mercury vapour arc lamp for the effective production of UV radiation (Ellis, 1991). Subsequently it was discovered that quartz possessed a high transparency in the UV range, coupled with a low coefficient of expansion and high melting point, which enabled it to be employed as a near-ideal envelope for UV lamps and much encouraged the research into the application of UV radiation for water disinfection (Jepson, 1973). Cernovodeau and Henri (1910), working at Marseilles, were credited by Jepson as being the first people to use UV for the disinfection of water. UV installations to treat drinking water on ships have been in use since 1916, but reports of problems with these continued for some time (US Department of Health, Education and Welfare, 1977a, b). Between 1916 and 1928, there were at least four water treatment plants employing UV disinfection in the U.S. although, in competition with the rapidly growing popularity of chlorine in water treatment, UV never established any popularity, basically as a result of reliability and maintenance problems and cost (Jepson, 1973). Research continued, however, into the application of UV radiation as a germicidal agent, and in 1929 Gates published the results of his work using monochromatic radiation into the germicidally effective wave ranges of UV and later the association was made between the lethal wavebands and absorption by nucleic acids (Gates, 1929).

According to Bierck *et al.* (1996), the emergence of UV irradiation as an important wastewater disinfection alternative may be attributed to the drawbacks of conventional chlorination, improvements in UV technology, and advances in the understanding of the UV process. The major problems associated with chlorination are effluent toxicity and safety. As a result, containment and scrubbing facilities are required for gaseous chlorine application (WEF, 1993). Dechlorination and containment facility requirements have increased the cost of chlorine-based disinfection. In the mean time, the development and application of open-channel, modular systems have reduced the cost of UV disinfection. Consequently, the costs of the two processes are comparable for new facilities (Putnam *et al.*, 1993).

In response to these developments, the frequency with which UV has been selected for disinfection has increased in recent years. Among U.S. wastewater treatment plants (WWTPs), only about 50 used UV disinfection in 1986 and most of these facilities had relatively small flows (Q<1 mgd). By 1990, more than 500 WWTPs had adopted UV disinfection, and a significant fraction of them at large facilities (Q>10 mgd). Today, more than 1000 WWTPs in North America have chosen UV irradiation for wastewater disinfection (Bierck *et al.*, 1996).

2.2 FUNDAMENTALS

2.2.1 Ultraviolet Radiation Spectra for Disinfection

As shown in **Figure 2-1**, the ultraviolet region of the electromagnetic spectrum is generally defined as that with wavelengths greater than the longest X-ray and less than the shortest wavelength visible to man (Stover *et al.*, 1986).

UV radiation comprises a section of the electromagnetic spectrum with wavelengths between 15 and 400 nm of which it is only the section between about 200 and 310 nm which is microbiocidal, with a definite lethal intensity peak existing at about 255 nm. On either side of the peak, both at shorter and longer wavelengths, the germicidal potential of the radiation falls off quite dramatically (Mecksner, 1987; Jepson, 1973; Meulemans, 1987; Sedgwick,

1976). Mecksner (1987) suggested that, within this waveband, radiation at about 295 nm causes sunburn. Those of about 260 nm will create conjunctivitis in man; those with a wavelength between 280 to 300 nm give rise to vitamin D; and the longer wavelengths between 300 and 400 nm give rise to skin browning. More systematically, UV radiation is divided into: UVa - 400 nm to 315 nm; UVb - 315 nm to 280 nm; UVc - 280 nm to 200 nm. The region below 200 nm is strongly absorbed by air and is often referred to as vacuum-UV (Meulemans,1987).

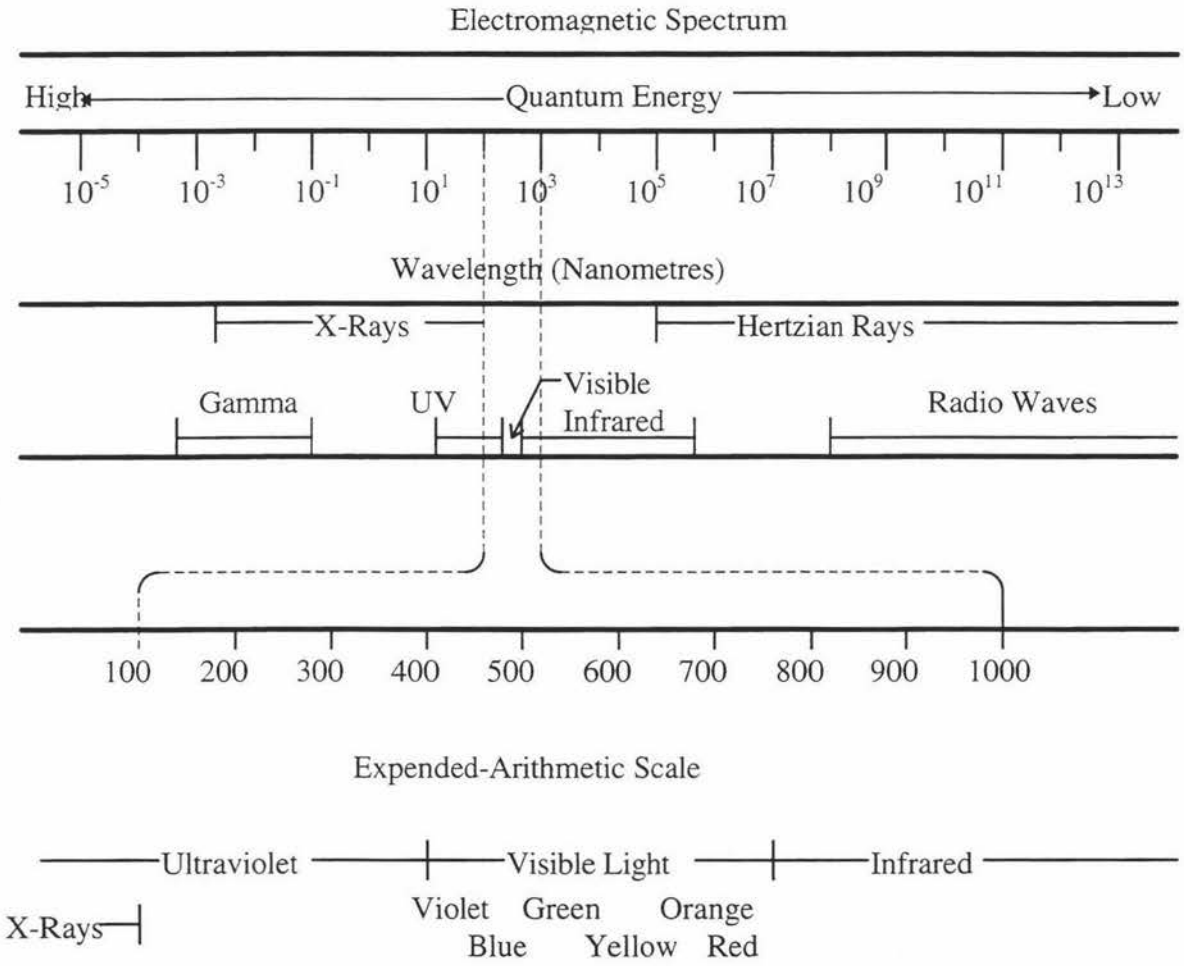

Figure 2-1 Electromagnetic Spectrum (adapted from Stover *et al.*, 1986)

As described by Bierck *et al.* (1996), ultraviolet irradiation is a physical disinfection process, and as such, it has several fundamental characteristics that distinguish it from chemical disinfection processes (such as chlorination). As described later, ultraviolet irradiation

achieves disinfection by inducing photochemical changes within the microorganisms. Two conditions must be met for a photochemical reaction to take place:

- Radiation of sufficient energy to alter chemical bonds must be available, and
- Such radiation must be absorbed by the target molecule (organism).

The energy associated with electromagnetic radiation may be calculated as

$$E_\lambda = \frac{hC}{\lambda} A \qquad (2\text{-}1)$$

where

E_λ = radiant energy associated with given wavelength, kcal/einstein;
C = speed of electromagnetic radiation in a vacuum = 3.00×10^{17} nm/s;
h = Planck's constant = 1.583×10^{-37} kcal·s;
λ = wavelength of electromagnetic radiation, nm; and
A = Avogadro's number $\approx 6.023 \times 10^{23}$ photon/einstein.

(Note : In a photochemical reaction, one einstein represents one "mole" [Avogadro's number] of photons. Photochemical reactions almost always proceed via interactions between single photons and single molecules. Therefore, an expression of radiation energy per einstein allows direct comparison with bond energies per mole.)

Equation 2-1 can be used to show that radiation at 253.7 nm has an associated energy of 112.8 kcal/einstein. A comparison of this value with the bond energies of several important bonds in microbial systems (**Table 2-1**) reveals that radiation at 253.7 nm is sufficiently energetic to induce photochemical change.

Table 2-1 Bond energy of importance in microbiological systems (March, 1985)

Bond	Bond dissociation energy, kcal/mole
O-H	110-111
C-H	96-99
N-H	93
C=O	173-181
C-N	69-75
C=C	146-151
C-C	83-85

As described later, photochemical change is only possible if radiation energy is made available by absorption. Extensive research has shown that nucleic acids (such as DNA and RNA) and proteins are effective absorbers of UV radiation (Jagger, 1967). In particular, these materials absorb strongly over the range $240 \leq \lambda \leq 260$ nm. Because low-pressure mercury arc lamps emit the majority of their radiation at a wavelength within this range, they can be used effectively to induce a photobiochemical change in microorganisms.

2.2.2 UV Disinfection Mechanisms

As described by Stover *et al.* (1986), the most effective spectral region for germicidal activity lies about the 260 nm wavelength. This is demonstrated on **Figure 2-2** which presents relative germicidal effectiveness as a function of wavelength (Oda, 1969). The action spectrum of nucleic acids is very similar to this, as shown by **Figure 2-3**. On a relative scale, the extinction coefficients (a measure of the inhibiting effect on bacterial colony formation) are plotted as a function of wavelength. Maximal effect occurred between the wavelength of 250 nm and 265 nm. Overlaying this is the relative percent absorption for a solution of RNA. The similarities are striking, supporting the premise that the lethal effects of UV radiation are induced by the photochemical damage to the cell's nucleic acids.

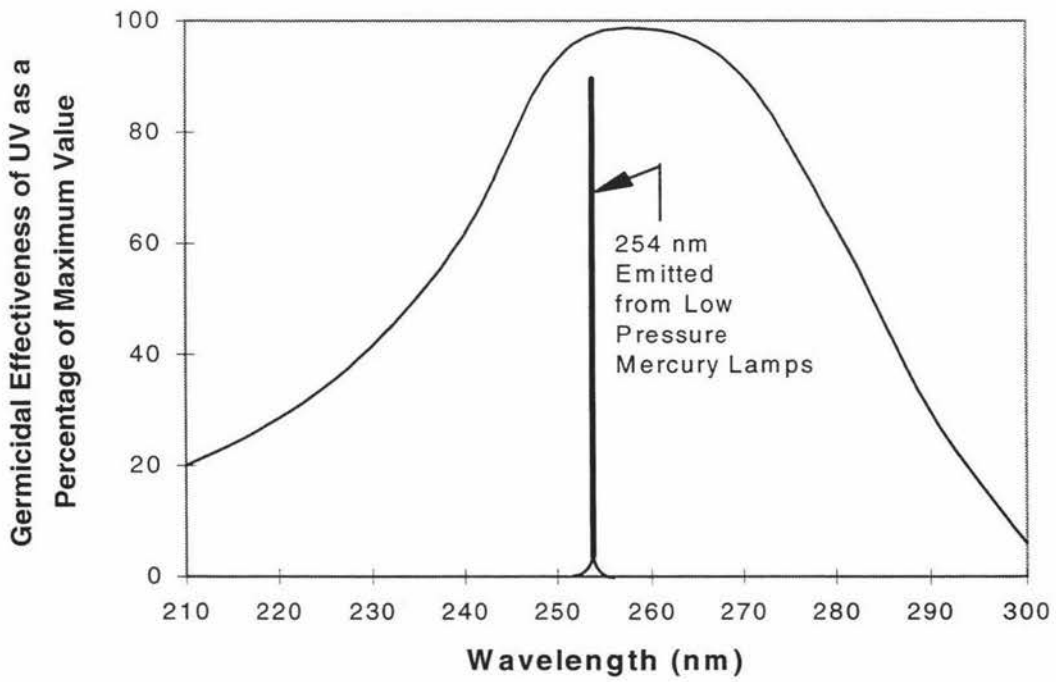

Figure 2-2 Relative germicidal effectiveness as a function of wavelength (Oda, 1969)

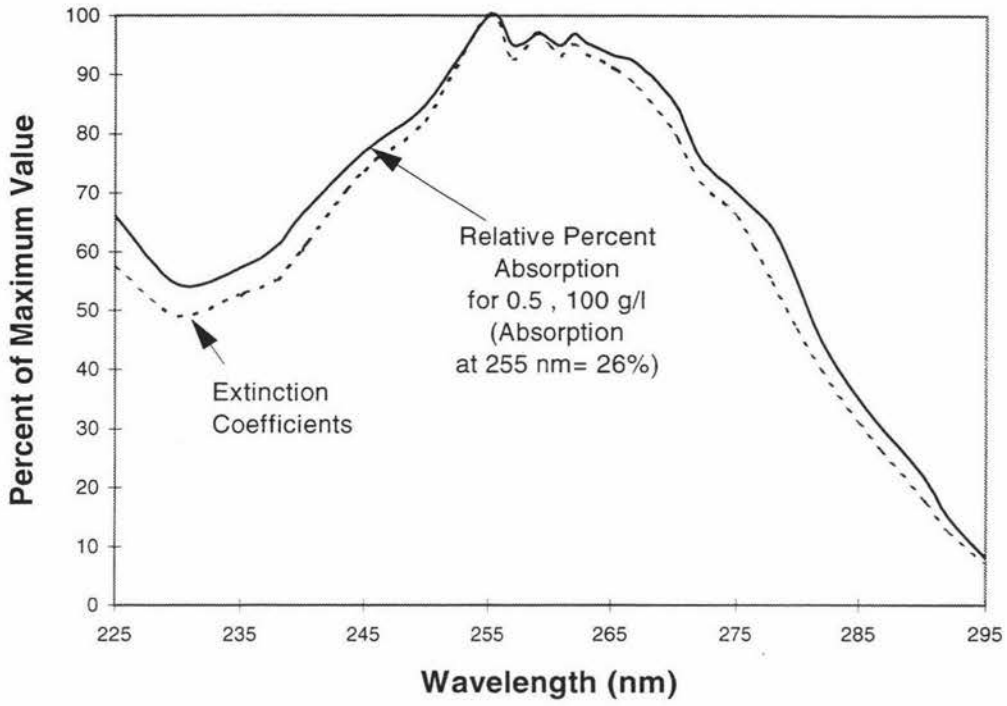

Figure 2-3 Relative abiotic effects of UV on E. coli compared to relative absorption of ribose nucleic acid (Loofbourow, 1948)

According to Stover *et al.* (1986) the photochemical changes induced by UV radiation on the DNA of an organism have been thoroughly studied. The adverse effects on cells result primarily from photochemical damage to nucleic acids - particularly to deoxyribonucleic acid (DNA) - which absorb strongly at or about 260 nm (Ellis, 1991). Energy dissipation reportedly causes disruption of unsaturated bonds which appears to produce a progressive lethal biochemical change (Sedgwick, 1973). Johansen and Myhrstad (1978) reported that lethal, or sublethal, effects are caused by damage to proteins, nucleic acids, and nucleic acid components of which it is the purine and pyrimidine bases that absorb particularly strongly in this range, with the most frequent effect being the production of thymine dimers. Secondary effects may include DNA strand breakages, as well cross-linking between DNA and DNA strands, between DNA and proteins, and between RNA and proteins. In addition, hydrates may be coupled to DNA molecules disturbing the genetic code and hence DNA replication. Some cellular change may also occur, including reduced DNA synthesis as a result of dimer production, reduced RNA and protein synthesis, and reduced mitosis as a result of protein damage.

Stover *et al.* (1986) stated "although several mechanisms exist, the most dominant is the dimerization of two pyrimidine molecules". To visualise this effect, consider the schematic representation of the DNA molecule on **Figure 2-4**. Recall that the DNA is a long polymer comprised of a double helix chain of simple monomeric units called nucleiotides. The order of these nucleotides constitutes the genetic information of the cell. These are represented on the figure by the letters A (adenine), G (guanine), C (cytosine) and T (thymine).

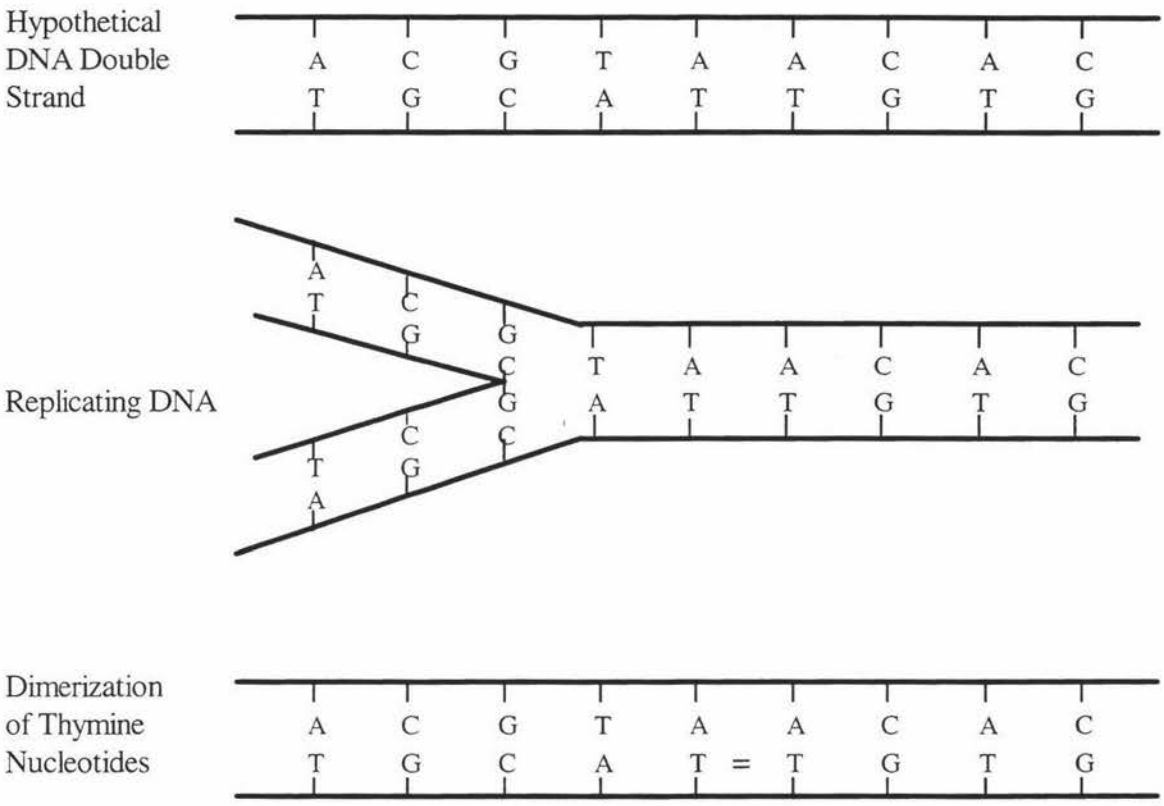

Figure 2-4 Examples of DNA and UV damage to DNA (Stover *et al.*, 1986)

Stover *et al.* (1986) illustrated "In the two strands, G is always opposite C and T is opposite A; if damage occurs in one strand the information still remains in the second strand. Thus, to repair the damage, a C is inserted opposite a G and a T opposite an A, and so on. As long as the information is retained on one strand, the second strand damage can be rebuilt. These are enzymatic processes. Before cell division occurs, a duplicate of the DNA is prepared by building a complementary strand to each of the parental strands. The UV induced dimer between two adjacent pyrimidines in a polynucleotide strand has been demonstrated for all

combinations of the pyrimidines (thymine, cytosine, and uracil). The thymine dimer is formed with the greatest efficiency, however. This is shown on **Figure 2-4.** There are two adjacent thymine monomers on one of the strands; during exposure to UV light new bonds are formed between the two such that a double thymine molecule, or dimer, is formed. Formation of many dimers along a DNA strand makes replication very difficult."

No comparable interactions of the purines have been demonstrated. The effect of the pyrimidine dimerization is a blocking of normal replication. Total and permanent inhibition of DNA replication would in itself be a lethal event (Stover *et al.*, 1986). Alternatively, replication may bypass such a distortion, producing an error in the copy and subsequent mutant daughter cell which is unable to replicate.

2.2.3 Possible Recovery from Inactivation

As stated by Bierck *et al.* (1996), microorganisms have evolved and developed effective biochemical systems for repairing damage caused by hostile environmental conditions, such as exposure to disinfectants. Repair and recovery of sublethal damage is known to occur following all disinfection operations.

Under some circumstances, the photobiochemical damage to an organism caused by UV irradiation can be repaired. These repair mechanisms allow UV-inactivated micro-organisms to regain viability following the disinfection process. Two principal repair mechanisms have significance relative to UV disinfection: photoreactivation (PR) and dark repair (Bierck *et al.*, 1996).

2.2.3.1 Photoreactivation

"Photoreactivation is a process whereby dimers within microbial nucleic acids are catalytically repaired to their original monometric forms" (Bierck *et al.*, 1996). Lindenauer and Darby (1994) summarised the current theory regarding the mechanism of photoreactivation. Reviews were also provided by Harm (1975) and Stover *et al.* (1986). Observations of the photoreactivation behaviour can be explained using a two-step reaction

mechanism (**Figure 2-5**). In the first step, a photoreactivating enzyme (PRE) combines with a pyrimidine dimer to form a PRE-dimer complex. The kinetics of this reversible reaction are such that the forward reaction (complex formation) is favoured over the reverse reaction. Step 1 is a strict chemical reaction and, as such, requires no radiation to take place. In step 2, the PRE-dimer complex absorbs radiation (310 nm < λ < 490 nm), resulting in a photolytic reformation of the pyrimidine monomers and release of PRE. Reformation of the monomers results in reversal of photochemical damage. Once released from the PRE-dimer complex, PRE is available for further complex formation and photolytic repair.

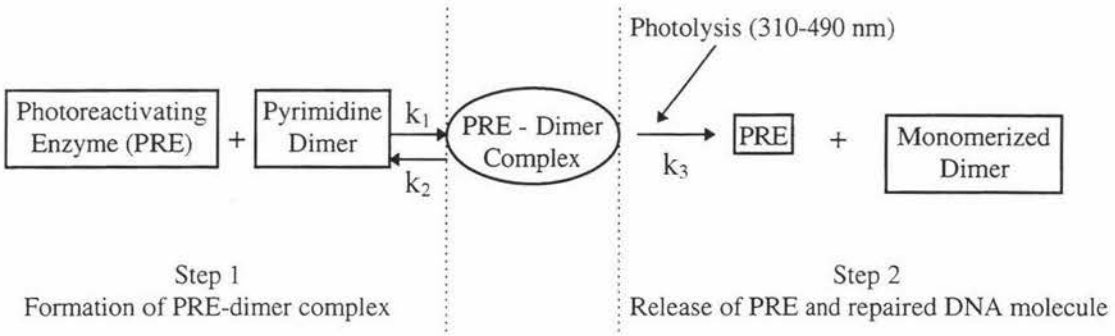

Figure 2-5 Hypothesized photoreactivation reaction mechanism (Harm, 1975, and Lindenauer and Darby, 1994)

According to Bierck *et al.* (1996) the significance of photoreactivation will depend in large part on the initial dose of inactivating (UV) radiation, the dose of photoreactivating radiation, and the microorganism. As the UV dose increases, an exposed microorganism will accumulate more damage in the form of pyrimidine dimers. Therefore, reversal of that damage (sufficient to allow reactivation) will depend on the availability of photoreactivating radiation and PRE. Although most commonly associated with bacteria, photoreacitvation has been observed in all taxonomic orders, including viruses (when in a host cell) (Jagger, 1967). However, some organisms do not demonstrate photorepair under field conditions (Lindenauer and Darby, 1994).

An inverse relationship was observed between average UV dose and faecal coliform UV photoreactivation by Lindenauer and Darby (1994). Elevated suspended solids concentrations resulted in increased photoreactivation, probably attributable to shielding of

organisms. The dose of photoreactivating light was also seen as an important parameter in the photoreactivation process (Lindenauer and Darby, 1994).

2.2.3.2 Dark repair

Dark repair provides a second mechanism for repairing photobiochemical damage. Dark repair processes are thought to involve enzymatic recognition of a dimer on a DNA strand. The dimer is excised from the DNA molecule, and the strand is repaired (Stover *et al.*, 1986). It is thought that dark repair processes have the ability to repair photoreactive and nonphotoreactive damage (Jagger, 1967).

2.2.3.3 The significance of repair mechanisms

As described by Bierck *et al.* (1996), the existence of repair mechanisms for UV-induced damage opens several ongoing questions. The primary one is to what extent these mechanisms should be taken into consideration during design. From an operational perspective, the availability of repair mechanisms would dictate a larger UV dose than would be required if no repair were possible. Similarly, the inclusion of reactivation mechanisms in the design process requires more UV hardware. Lindenauer and Darby (1994) suggested in their analysis that the effect of photoreactivation is relatively insignificant at the dose levels they interpreted (that is, reuse applications at doses greater than 60 to 80 $mW \cdot s/cm^2$). However, much of the design work for secondary WWTPs has been at equivalent dose levels of less than 40 $mW \cdot s/cm^2$, at which point significant increases in residual densities have been measured (via the static light/dark bottle technique) (Stover *et al.*, 1986).

Lehrer and Cabelli (1993) pointed out that the aetiologic agents of the most common waterborne disease are Norwalk-like viruses. Many of these viruses are not thought to undergo repair of UV-induced damage. UV inactivation of such viruses has been shown to be quite effective, especially when compared with chlorine-based disinfection processes (Yip and Konasewich, 1972).

Whitby and Palmateer (1993) suggested that this phenomenon is not observed *in situ*. Using

labeled *E. Coli* bacteria they demonstrated a lack of reactivation in UV-irradiated wastewater effluent after release to a receiving stream. These same bacteria were shown to undergo photoreactivation when exposed to a sufficient dose of photoreactivating radiation under controlled conditions. One possible explanation for this discrepancy is that organisms released to receiving water body did not receive a sufficient dose of photoreactivating radiation to undergo repair. The dose of photoreactivating radiation received by organisms in wastewater effluent will be site-specific and will depend on factors such as water quality, receiving water depth, and dilution in receiving water (Bierck *et al.*, 1996).

Chan and Killick (1995) investigated the influence of salinity and temperature on both the rates of dark repair and photoreactivation of *E. Coli* exposed to a sublethal dose of UV radiation. They concluded that less reactivation by *E. Coli* is likely within UV treated effluent disposed of into coastal environments. Johansen *et al.* (1978) suggested that the need to protect UV-irradiated water from sunlight is evident, as is the requirement to design for overdose. Angehrn (1984) did not believe the reactivation and repair processes are possible under operational conditions and suggested that they can only be brought about under laboratory conditions utilising increased temperature and extended exposure to light of greater than 300 nm wavelength. While the study of Whitby and Palmateer (1993) demonstrated that photoreactivation may not always be significant, Bierck *et al.* (1996) warned that designers of UV systems should understand that reactivation can occur under certain environmental conditions.

One design approach regarding the inclusion of recovery mechanisms has been the increased level of UV dose. For example, the reuse work in California has used the equivalent doses on the order of 60 to 100 $mW \cdot s/cm^2$ to account for the photoreactivation (Bierck *et al.*, 1996).

It is important to note that, although many operating UV disinfection systems in WWTPs have been designed and are operating successfully with or without consideration of repair mechanisms, one should be cautioned that this does not mean repair is not occurring, but that it may be masked by overdesign, underuse (WWTPs are well below their design capacity), and sampling/analysis techniques (Bierck *et al.*, 1996).

2.3 FACTORS AFFECTING UV DISINFECTION

As discussed below, the disinfection of water by UV radiation depends on a number of factors. Principally, these are the emission spectrum of the UV source, the effective dose which is a function of the intensity of the irradiation and the period of exposure, the sensitivity of the various microorganisms involved, and the performance of the reactors. The intensity of the irradiation will be affected to some extent by the ageing of the UV source and also, to a substantial extent, by the quality of the water, which in this case relates to the transparency of the water under treatment to the lethal wavelengths of the UV radiation.

2.3.1 The Emission Spectrum of the UV Source

According to Bierck *et al.* (1996) the majority of UV disinfection applications have chosen the low-pressure mercury arc lamps as the source of UV radiation. Approximately 85% of the output from these lamps is monochromatic at a wavelength (λ) of 253.7 nm (**Figure 2-6a**).

Alternative sources of UV radiation are also being investigated for disinfection processes. In particular, medium-pressure mercury arc lamps have been used for disinfection in some applications (Bierck *et al.*, 1996). The output spectrum of these lamps is substantially different from the spectrum of conventional low-pressure lamps (see **Figure 2-6b**). Radiation is emitted from these lamps over a large fraction of the UV spectrum. As a result, the responses of microorganisms to radiation from these lamps may be more complex than the responses elicited by exposure to radiation from low-pressure lamps. Further more, a theoretical analysis of photobiochemical change induced by medium-pressure lamps is more complex because of the polychromatic nature of the radiant energy source. However, Bierck *et al.* (1996) stated that the fundamental operation of disinfection processes that employ these lamps is conceptually similar to the operation observed for conventional low-pressure mercury arc lamps.

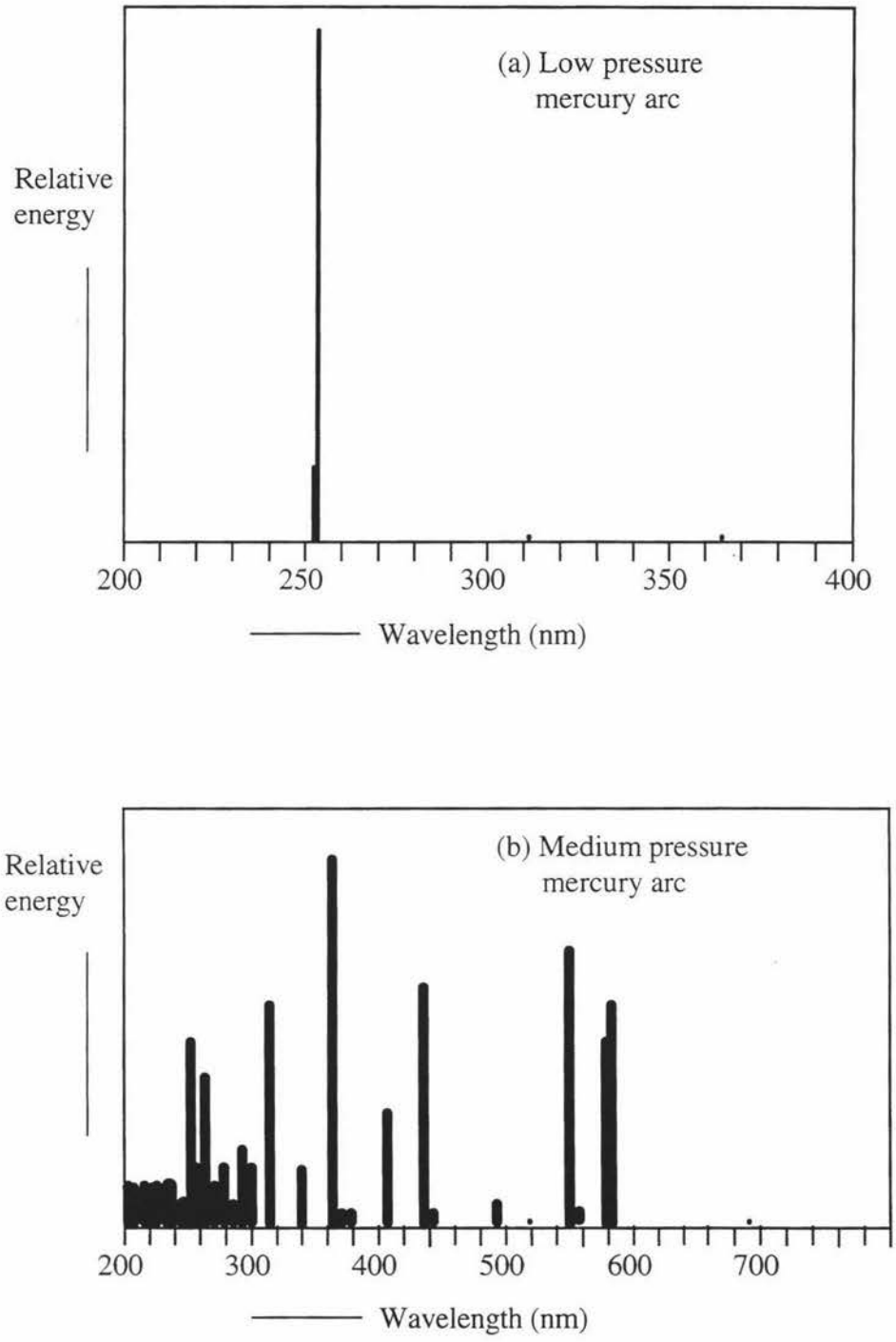

Figure 2-6 Radiant power output spectra from (a) low-pressure and (b) medium-pressure mercury arc (Meulemans, 1987)

2.3.2 UV Doses for Microorganism Inactivation

The germicidal effectiveness of UV radiation can be represented by the survival ratio (N/N_0), which can be approximated at any given time by an exponential function

$$\frac{N}{N_0} = \exp(-k \cdot I_{effect} \cdot t) \qquad (2\text{-}2)$$

in which N_0 = initial count of specific species of microorganism; N = final count of specific species of microorganism; I_{effect} = effective irradiation (W/m^2); t = time (seconds); k = inactivation rate constant depending on sensitivity of the specific species and exposure intensity; $I_{effect} \times t$ = exposure or dose (J/m^2). The practical consequence of this log function is that if it is wished to decrease the survival ratio from 0.1 to 0.01 then the exposure (or dose) will have to be doubled.

2.3.2.1 Sensitivity of microorgnisms to UV inactivation

Since there is considerable variation in the sensitivity of microorganisms to UV radiation, the constant k will possess a range of values depending on which microorganism is under consideration. Spores, cysts, and algae are particularly difficult to inactivate with UV, and Mechsner (1987) reported that the relative sensitivity of various bacteria is in the order *Salmonella* spp.> *Shigella* spp. > *E. coli, Streptococcae* > *Bacterium prodigiosum, Pseudomonas fluorescenes* > *Bacillus proteus* » *Bacillus* spores. Generally, Gram-positive bacteria containing a thick capsule are more difficult to inactivate than the thinner-walled Gram-negative bacteria. Viruses possess sensitivities to UV similar to many bacteria. Algae may require hundreds of times more energy than bacteria to bring about their destruction. **Table 2-2**, presented in a simplified form from the paper by Meulemans (1987), gives typical values for the exposure necessary to bring about a survival ratio of 0.1. Should a survival ratio of 0.0001 be required, for example, it would be necessary to multiply the stated exposure by a factor of four. Normally, a minimum exposure of between 160 and 250 J/m^2, depending on the country, is considered to be sufficient. Recently reported dose-response behaviours of different organisms (Wilson *et al.*, 1992; Cairns, 1991; Wolfe, 1990) were summarised by Bierck *et al.* (1996). From these dose requirements for 90% inactivation, Bierck *et al.* (1996) concluded that, generally speaking, viruses and bacteria are inactivated

effectively by UV irradiation, whereas protozoan cysts and spore-forming bacteria are relatively resistant to inactivation.

Table 2-2 Approximate dose requirement to achieve a survival ratio of 0.1 at 253.7 nm (Meulemans, 1987)

Microorganism	Dose (J/m^2)
Bacteria	
E. coli	30
Eberthella Typhsa	21
salmonella enteritis	40
Shigella dysenteriae	22
Staphylococcus aureus	26
Bacillus subtilis	70
B. subtilis (spores)	120
Yeasts	
Saccharomyces ellipsoideus	60
Torula sphaerica	23
Algae	
Green algae	3600-6000
Protozoa	
Paramecium	640-1000
Mold spores	
Aspergillus amstelodami	667
A. niger	1320
Cladosporium herburum	600
Penicillium digitatum	440
Rhizopus nigricans	1110

Wiedenmann *et al.* (1993) found that bacteriophage MS-2 required a UV dose approximately three times higher than that delivered to HAV to achieve similar inactivation. Bosch *èt al.* (1989) demonstrated rotavirus SA11, coliphage f2, *E. coli*, and *Strepotococcus faecalis* to bacteriophage active against *Bacteroides fragilis* when exposed to chlorine or UV irradiation. *B. Fragilis* bacteriophage was the most resistant organism to chlorine disinfection, while f2 coliphage yielded the highest resistance toward UV irradiation.

2.3.2.2 UV irradiation intensity

UV dose is a function of radiation intensity and exposure time. The intensity during exposure time is the rate, or flux, of delivery of photons to the target. The relationship

between UV radiation intensity and its adsorption is governed by Lambert's Law, i.e., equal fractions of the incident radiation are absorbed by successive layers of equal thickness of the light-absorbing material. For solutions, there is also Beer's Law, which states that equal fractions of the incident radiation are absorbed by equal changes in concentration of the absorbing substance in a path of constant depth, i.e.,

$$\frac{dI}{db} = kI \tag{2-3}$$

and

$$\frac{dI}{dc} = k' I \tag{2-4}$$

therefore on integration

$$I = I_0 e^{-kb} = I_0 10^{-ab} \tag{2-5}$$

for Lambert's Law and

$$I = I_0 \cdot e^{-k'c} = I_0 10^{-a'c} \tag{2-6}$$

for Beer's Law, where I_0 is the intensity of the incident radiation; I is the intensity of the radiation after passage through thickness b of absorbing material; k is the absorption coefficient; a is the molar absorptivity (sometimes the extinction coefficient); c is the concentration of the solution. Lambert's Law is always obeyed and Beer's Law is obeyed for most dilute solutions.

Combining the laws gives

$$I = I_0 \cdot 10^{-a \cdot b \cdot c} \tag{2-7}$$

and

$$I_{absorbed} = I_0 (1 - 10^{-a' \cdot b \cdot c}) \tag{2-8}$$

thus

$$\log \frac{I_0}{I} = a' \cdot b \cdot c = d \quad (optical\ density) \tag{2-9}$$

and the intensity of radiation (I) is measured in milliwatts per square meter. The optical density of water being irradiated by UV light will depend largely on turbidity, colour, and the organic content of water. Humic acid, phenol, lignin sulphate (effluents from paper mills), and iron (Yip *et al.*,1972) will all absorb UV radiation at the critical 255-nm wavelength (Ellis, 1991).

Zubrilin *et al.* (1991) used a krypton monofluoride laser (λ = 248 nm) to study inactivation of *E. coli*. Inactivation was found to be a function of UV dose but independent of intensity.

2.3.2.3 Exposure duration for effective UV disinfection

From **Equation 2-2** it can be seen that the exposure duration to achieve certain degree of inactivation is closely related to the sensitivity of the microorganisms and the effective UV radiation intensity, as well as the survival ratio.

In an investigation of the application of UV for the disinfection of seawater, Hill *et al.* (1971) used static tests to demonstrate the effectiveness and rate of inactivation for eight enteric viruses. They reported that the exposure duration required to obtain effective disinfection (99.9 percent reduction) at an applied intensity of 1160 $\mu W/cm^2$ was as follows:

Poliovirus 1	28 seconds
Poliovirus 2	31 seconds
Poliovirus 3	27 seconds
Echovirus 1	28 seconds
Echovirus 11	31 seconds
Coxsackievirus A - 9	31 seconds
Coxsackievirus B - 1	40 seconds
Reovirus 1	40 seconds

Maier *et al.* (1995) evaluated UV inactivation of the poliovirus by using polymerise chain reaction (PCR). The virus was irradiated with low-pressure mercury lamp. A four-log inactivation of the virus was completed after 300 seconds. The vital RNA was detectable by PCR even at irradiation times of 4000 seconds. Leveque *et al.* (1995) investigated the virucidal effect of UV light on hepatitis A virus in seawater. Infectious virus was no longer detectable after 15 minutes irradiation of 3 litres of experimentally contaminated water. Genomic amplification by PCR after reverse transcription allowed the detection of vial RNA in all samples even after 60 minutes irradiation.

However, as concluded in a review of the current technology and research needs, the contact times required for UV inactivation of viruses and bacteria was usually on the

order of seconds (Wolfe, 1990). For example, UVTA (1997) in comparing disinfection by UV and chlorine reported that UV disinfection is fast at 3 - 5 seconds. Bierck *et al.* (1996) reported the hydraulic detention time typical of the UV systems is less than 10 seconds.

2.3.2.4 UV Dose requirement for wastewater disinfection

To destroy pathogenic organisms it is necessary to introduce the proper dose of UV radiation into water. Part of the energy emitted from the source of radiation is absorbed by water according to Lambert-Beer's Law:

$$I = I_0 \exp(-\alpha b) \tag{2-10}$$

where:

I = intensity of the radiation passed through the water layers of b thickness;
I_0 = intensity of radiation emitted from the source;
b = the thickness of the water layer exposed to radiation;
α = absorption coefficient.

The bactericidal power necessary to disinfect water with UV radiation is calculated from the following formula (Sobotka, 1993):

$$F_u = \frac{Q \alpha D_{uv}}{\eta_1 \eta_2} \tag{2-11}$$

where:

F_u= bactericidal power needed for disinfection
Q = flow of water to be disinfected;
α = absorption coefficient;
D_{uv}= bactericidal dose;
η_1 = transmittance through quartz casing;
η_2 = coefficient of radiation energy utilization.

$$\eta_2 = 1 - e^{-\alpha(R-r)} \tag{2-12}$$

where:

R = device casing radius; r = quartz casing radius.

The bactericidal dose for most of the pathogenic organisms does not exceed 250 Ws/m^2 (or 25,000 $\mu W \bullet s/cm^2$). Absorption coefficient α does not depend on water layer thickness and

radiation intensity. At given UV rays length α depends only on water quality, mainly on its turbidity and colour (See **Section 2.3.4.2** for details).

Most bacteria and viruses require relatively low UV dosage for inactivation (**Table 2-2**) - usually in the range of 2000 to 6000 ($\mu W \bullet s/cm^2$ for 90% kill. However, protozoan cysts appear to be considerably more resistant to UV inactivation than other microorganism. Rice and Hoff (1981) showed that less than 80% of G. *lamblia* cysts were inactivated at UV dosages up to 63,000 $\mu W \bullet s/cm^2$. Carlson *et al.* (1985) demonstrated that 90% of G. *muris* cysts were inactivated when the dosage was increased to approximately 82,000 $\mu W \bullet s/cm^2$. These results are significant in light of the fact that the maximum designed dose of many commercially available UV units is 25,000 to 35,000 $\mu W \bullet s/cm^2$.

Although no information on the inactivation of *Cryptosporidium* by UV could be found in the literature, it is likely that the dosage would be higher than for *Giardia*, given the extreme resistance of *Cryptosporidium* to chlorine. Based on the bacterial and viral results, the U.S. Department of Health, Education and Welfare issued a 1966 policy statement in which the criteria for the acceptability of UV disinfecting units were stated as a minimum dosage of 16,000 $\mu W \bullet s/cm^2$ and a maximum water depth of approximately 7.5 cm (National Academy of Science, 1980). This statement has formed the basis for a world wide standard.

Using UV radiation at 254 nm, Masschelein *et al.* (1989) found that the dosage necessary for 99% inactivation of f2 coliphage was 470 ± 30 J/m^2 (or $47{,}000 \pm 3{,}000$ $\mu W \bullet s/cm^2$). Watts *et al.* (1989) calculated an empirical efficiency factor and estimated the UV light intensity for the determination of reaction rate profiles with respect to water depth for indirect photolysis system.

Darby *et al.* (1993) reported that UV disinfection achieved California's restrictive standards for wastewater reuse. Using a pilot-scale system, they were able to show that filtered and unfiltered secondary effluents could be disinfected to meet a 7-day median maximum of 23 total coliform/100 mL with UV doses of 48 and 60 $mW \bullet s/cm^2$, respectively. Furthermore, exposure of the filtered effluent to a dose of 97 $mW \bullet s/cm^2$ allowed compliance with the 7-day median maximum of 2.2 total coliform/100 mL. Awad *et al.* (1993) reported the results

of an extensive pilot investigation into the application of UV disinfection for reuse according to California's "Title 22" standards. Using a calculated UV dose of 120 mW•s/cm^2, they were able to produce water that had bacterial and viral concentrations which were consistently below the limits of detection. The only significant change in water chemistry resulting from these high dosages was a two-log reduction in 8- to 16-carbon hydrocarbons. Chen *et al.* (1993) also evaluated UV for compliance with Title 22 regulations. A dose of 100 to 140 mW•s/cm^2 was required to meet bacterial and viral quality criteria. Essentially no change in water chemistry was observed to result from UV irradiation. Braunsein *et al.* (1996) assessed a field UV disinfection system in terms of the most stringent U.S. wastewater reuse standards. The UV inactivation of total and faecal coliform bacteria and seeded MS2 coliphages in filtered activated sludge effluent was treated continuously for 22 weeks. The most stringent coliform criterion, that the 7-day median not exceed 2.2 per 100 mL, was met consistently in effluent exposed to an average UV dose of 168 and 112 mW•s/cm^2 for total and faecal coliforms, respectively. MS2 coliphages were more resistant to UV disinfection than the coliform group.

UVTA (1997) reported the following dose requirements for killing microorganisms:

Bacteria:	2,500 - 26,400 μWs/cm^2
Yeast:	6,600 - 17,600 μWs/cm^2
Algae:	11,000 - 33,000 μWs/cm^2
Viruses:	2,500 - 22,000 μWs/cm^2

From the reported UV doses for effective disinfection, it can be seen that the required UV dose depends on not only the sensitivity of the microorganism(s), but also the water quality standard for discharge. Because the required UV dose is a function of the survival ratio (N/N_0), the employment of a stringent water quality standard (i.e., lower N/N0) may imply a significant increase in UV dose.

2.3.3 The Performance of UV Reactors

The efficiency of disinfection in a wastewater treatment plant is a function of the performance of the UV reactors employed. These may include the design of the UV equipment, the hydraulic behaviour of the reactor, and the maintenance of the system.

2.3.3.1 Current ultraviolet equipment

According to Bierck *et al.* (1996), original systems offered by vendors in the early 1980s consisted of enclosed chambers employing either a submerged-lamp system or a noncontact lamp system. The technology evolved to a modular, submerged-lamp system installed in an open channel, which significantly improved system maintenance and afforded better hydraulics. The modular, open-channel UV system using a conventional low-pressure mercury arc lamp is currently the industry standard. As reported by Bierck *et al.* (1996), an estimated 80% of all UV systems in operation in 1996 are open-channel, low-pressure lamp systems, and they consisted nearly all of the recent and new installations. The development of the electronic ballast available from 1991 offered a major improvement to these systems. The current emphasis in the market is research and development of alternate high-intensity UV sources, which fall into two basic categories: high-intensity low-pressure lamp systems and medium-pressure lamp systems. Changes in lamp physics allow each of the new systems to provide similar germicidal performance, with substantial reduction in the number of lamps used compared to conventional low-pressure lamp systems.

Low-Pressure Mercury Lamp Systems. The low-pressure mercury arc lamp produces UV radiation by means of an electric discharge through a mixture of mercury vapour and argon at a controlled subatmospheric pressure (0.007 mmHg [torr]). It is the most common lamp used for wastewater disinfection. It has the longest history of the three major lamp types. This lamp has been the industry standard since the introduction of UV disinfection systems and accounts for more than 99.9% of the UV installations in the U.S. and Canada (Bierck *et al.*, 1996).

While the low-pressure lamp is efficient at producing effective germicidal radiation, its intensity is relatively low. The UV output is 0.18 W of UV per centimetre of arc length (Bierck *et al.*, 1996).

Low-pressure lamp systems have become increasingly reliable from both an operational and a performance standpoint, to the point where reliability is generally no long a factor

in comparison with other disinfection technologies (Bierck *et al.*, 1996). Effective lamp lives have increased from approximately 7500 hours for the first-generation closed-shell reactors to greater than 13 000 hours for the open-channel, full-submergence systems. This resulted in longer relamping intervals and lower operating costs. Closed-shell and noncontact low-pressure lamp systems are no longer manufactured for wastewater applications (Bierck *et al.*, 1996). Open-channel systems fall into two major categories: horizontal and vertical (**Figure 2-7**).

Medium pressure UV lamps were demonstrated by Gehr *et al.* (1993) to be effective for disinfection of a low quality effluent from a physicochemical treatment plant. Collimated beam and pilot-scale tests confirmed the ability of medium-pressure UV lamp systems to inactivate faecal coliform bacteria. The behaviour of high-intensity, low-pressure lamps was compared with conventional low-pressure technology in pilot testing as described by Parsons and Scheible (1993). Both systems performed well, but the high-intensity system can operate with as few as 10% of the lamps required in a conventional low-pressure system. This characteristic makes the high-intensity system particularly well suited for disinfection of low quality waters.

As reported by Bierck *et al.* (1996), open-channel, modular, horizontal UV lamp configurations are the most prevalent systems in the municipal wastewater industry. The first of its kind went to full-scale operation at a WWTP in Canada in 1982. Horizontal lamp systems consist of lamp bundles that are suspended from modular racks in planes parallel to the channel floor. Most suppliers in this category provide systems with lamps that are parallel to the direction of process flow.

Open-channel, modular, vertical UV systems have been operating in the municipal wastewater field since 1987 (Bierck *et al.*, 1996). They consist of lamp bundles that are secured in an open rectangular frame. The frame rests on the channel bottom in an upright position (lying on one of its short faces), such that the lamps are perpendicular to the channel floor.

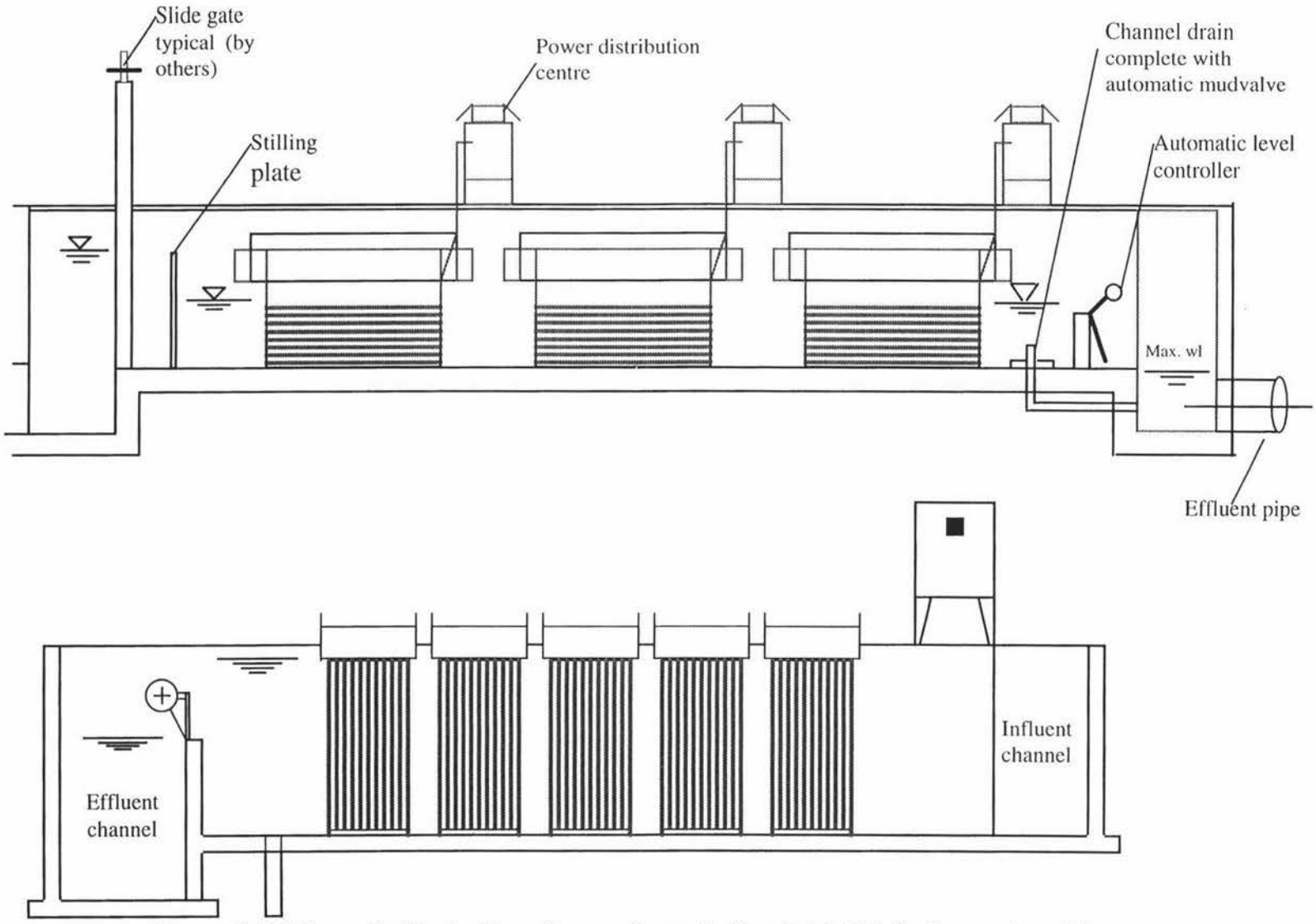

Figure 2-7 Schematic illustration of open-channel ultraviolet disinfection system. Top, horizontal lamp configuration; bottom, vertical lamp configuration (Bierck *et al.*, 1986).

Medium-Pressure Mercury Lamp Systems. Medium-pressure lamps employ the same basic principle as low-pressure lamps. The major difference is that the mercury vapour emission is carried out at significantly higher lamp pressures and temperatures (Bierck *et al.*, 1996). It operates in the 100 to 10 000 torr (mm Hg) range, which is at or near atmospheric pressure. Its operating temperatures range from 600 to 800°C, which is 10 to 20 times higher than the standard operating temperature range of 40 to 60°C for low-pressure lamps. Unlike the low-pressure lamp, the wastewater temperature has no impact on the medium-pressure lamp operating temperature.

The UV output of a medium-pressure lamp is 50 to 80 times higher than that of a low-pressure lamp. UV output is typically on the order of 9.1 to 14.2 W/cm arc length. However the radiation produced is polychromatic and ranges from the lower end of the germicidal range (200 nm) to red visible (700 nm). While the 30 to 40% conversion of input energy to radiation is similar to that of low-pressure lamps, only 25% of the energy is in the germicidal range. The net effect is that the conversion of input energy to germicidal energy is 5 to 7% for medium-pressure lamps, compared to 30 to 35% for low-pressure lamps (Bierck *et al.*, 1996).

Medium-pressure lamps have a rated life of 4,000 hours, though an expected life exceeding 8 000 hours has been experienced. The major advantage of the medium-pressure system is the lower capital cost of installation. A second advantage is the decreased requirement for lamp cleaning resulting from the significantly reduced number of lamps. The major disadvantage is the high operation and maintenance costs (exclusive of lamp cleaning). Experience with medium-pressure lamp system is limited (Bierck *et al.*, 1996).

Low-Pressure, High-Intensity Systems. According to Bierck *et al.* (1996), the aim of the low-pressure, high-intensity lamp is to incorporate the beneficial features of the conventional low-pressure and medium-pressure lamp system: specifically, the nearly monochromatic germicidal light produced by conventional low-pressure lamps and the high-intensity levels characteristic of medium-pressure lamps. It operates in the pressure range of 0.01 to 0.001 mmHg and temperature range of 180 to 200°C.

2.3.3.2 The ageing of UV lamps

Ultraviolet output from mercury arc lamps changes as a function of time. In general, lamps begin with a relatively high output power. Lamp output falls sharply in the first 1,000 to 2,000 hours of operation, followed by a more gradual decline up to the point of failure (**Figure 2-8**). The recommended operating life of a mercury arc lamp is generally 7,500 to 8,000 hours; however, a recent survey of 30 operating facilities revealed that an operating life of greater than 14,000 hours can be expected for low-pressure mercury lamps (U.S.EPA, 1992).

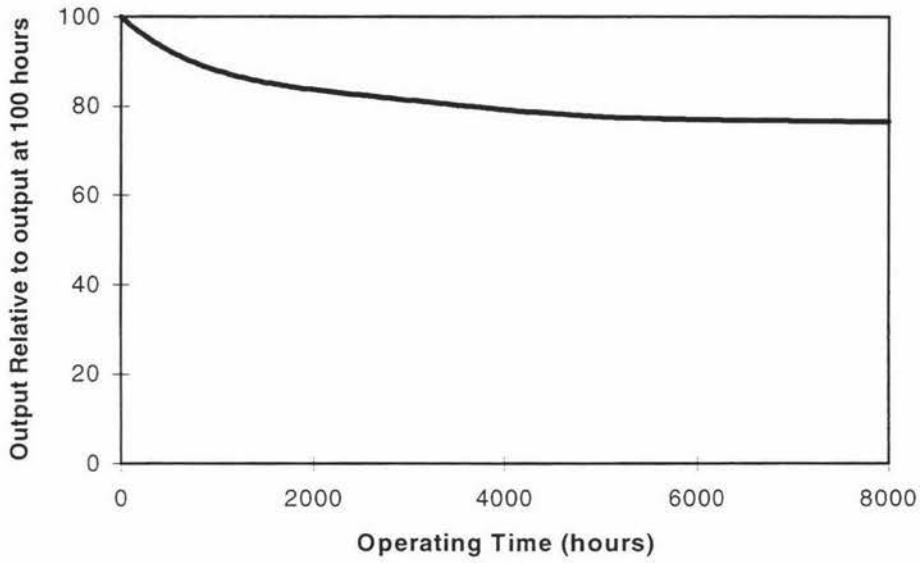

Figure 2-8 Typical ultraviolet lamp output as a function of time (Bierck *et al.*, 1996)

System output can be kept relatively uniform if a schedule of staged lamp replacement is implemented.

Lamp wall temperature is also known to affect output, with an optimum level of between 35 and 50°C (Stover *et al.*, 1986). Generally, holding lamp wall temperatures between 45 and 50°C will maintain maximum output from the lamp. Liquid temperatures between 15 and 25°C will typically result in lamp temperature conditions that are optimum (greater than 85% maximum output), with outputs falling significantly at liquid temperatures above or below this range (Bierck *et al.*, 1996). The electronic

ballast now being installed with all new systems can provide variable power input to the lamps, which can affect the lamp operating temperature. Manufacturers now offer a range of ballast designs. With constant liquid temperatures, higher flow will drive the lamp temperature up and vice versa. Thus, the impact of liquid temperature on lamp output can be offset by the ballast input, suggesting that lamp output can be held near optimum over a wide range of operating conditions.

2.3.3.3 Fouling and cleaning of UV lamp jackets

As discussed earlier, dissolved and particulate materials in the liquid phase may impede radiation transmission. Another factor that can limit radiation delivery is the accumulation of insoluble materials on the surface of the quartz jackets that house the UV lamps.

According to Bierck *et al.* (1996), quartz jacket fouling matter can contain organic and/or inorganic constituents. Organic fouling is largely attributable to floatable materials that accumulate on lamp jackets near the free surface in open-channel systems. Control of organic fouling can be achieved by removal of these wastewater constituents in upstream processes.

Inorganic components of a fouling material will accumulate over the entire surface of a quartz jacket. Empirical observations have suggested that waters containing high hardness and/or high iron concentrations are likely to promote fouling (Bierck *et al.*, 1996).

Bierck *et al.* (1996) described a variety of techniques to control lamp fouling. Chemical removal of scale is achieved by applying a dilute acid (pH of approximately 1 to 2) to the fouled surface. Acid can be applied by either wiping the individual lamps or immersing entire lamp modules. A wide range of cleaning agents was found to be used (U.S.EPA, 1992). Citric acid and commercially available bathroom cleaners were used most commonly. Other agents included commercial detergents and dilute acids. Reported cleaning frequencies were highly site-specific and ranged from weekly to

yearly, with a median frequency of approximately once per month (U.S.EPA, 1992).

A number of physical processes can be incorporated to mitigate scaling. Introduction of air bubbles at the base of a channel for short periods but on a frequent basis (such as 10 minutes per day) has been shown effectively mitigated scale formation (Blatchley *et al.*, 1993). Automatic air sparging and ultrasonic dip tank for large lamp bundles were also used to clean the lamps.

2.3.3.4 The hydraulic behaviour of the UV reactor

According to Stover *et al.* (1986), the hydraulic behaviour of a UV reactor is affected by the flow and the design which determine the velocities and loading to the system. To achieve effective disinfection performance, the following must be considered in the hydraulic design:

1. The unit should be a plug flow reactor (PFR) in which each element of fluid passing through the reactor resides in the reactor for the same period of time;
2. The flow motion should be turbulent radially from the direction of flow to allow for each element of flow to receive the same overall average intensity of radiation in the non-uniform intensity field which exists in the reactor;
3. Maximum use must be made of the entire volume of the reactor, or conversely, dead spaces must be minimised, such that the effective volume is very close to the actual volume available.

2.3.3.5 Estimation of the average intensity in a UV reactor

Recall that the rate of inactivation k is described as a function of the intensity. By this fact it becomes important to be able to quantify the intensity in a given system. The intensity in a reactor is a function of the UV source (output), the physical arrangement of the source relative to wastewater (the arrangement of the lamps and their placement in or out of the liquid), and the energy sinks present which attenuate the source output before it can be utilized for disinfection purposes.

The UV source, as discussed earlier, is typically the low-pressure mercury arc lamp. The arrangement of the lamps is specific for an UV disinfection reactor.

In the quartz systems, the individual lamps are sheathed in quartz sleeves only slightly larger in diameter than the lamp and the entire lamp/quartz bundle is submerged in the flowing liquid. In systems where the wastewater dose not contact the quartz or lamp surface, separate conduits carry the wastewaters. The conduits are translucent to the UV light, with the lamps placed near the outside conduit wall.

Determining the intensity at any point in these complex lamp reactors is not straightforward (Stover *et al.*, 1986). There was no commercially available detector which can measure the true intensity in such a system. The problem lies in the fact that the detectors are planar receptors; only energy striking a flat surface will be measured. Such detectors will intercept fractions of light striking the surface at an angle. Only light which is normal to the surface, i.e., collimated light, however, will be wholly measured. Where light is not collimated, as is the case with a multi-lamp UV reactor, the flux of energy is three-dimensional.

Several approaches have been proposed to estimate light intensity, including chemical actinometry, biological assays, and direct calculation. The two procedures which have received greater attention are the bioassay and direct calculation methods.

The bioassay procedure has been applied in a limited fashion for a number of design specifications, primarily as a technique for quantifying the dose delivered by a specific piece of UV equipment. It can also be used to implicitly drive the intensity within a system. A detailed procedure and example of using the bioassay procedure to estimate UV dose and intensity was given by Stover *et al.* (1986).

The direct calculation of intensity is accomplished by the point source summation (PSS) method. The method yields the average intensity as a function of the UV absorbance coefficient of the wastewater.

Calculation of the Average Intensity by the Point Source Summation (PSS) Method

The point source summation technique was evaluated by Jacob and Dranoff (1970) for light intensity profiles in a perfectly mixed photoreactor and was first applied to UV disinfection reactors by Johnson and Qualls (1984). It presumes that the lamp is a finite series of point sources that emit energy radially in all directions. The intensity at a given

point in a reactor would be the sum of intensities from each of these point sources. The following description of the PSS method was taken from Stover *et al.* (1986):

Intensity Attenuation

UV intensity will attenuate as the distance from the source increases. This occurs by two basic mechanisms: dissipation and adsorption. Dissipation is simply the dilution of energy as it moves away from the source. The area upon which the energy is being projected is increasing; thus the energy per unit area is decreasing. This dissipation can be calculated by surrounding the point source by a sphere of radius R:

$$I = S/(4\pi R^2) \tag{2-13}$$

where I is the intensity at a distance R in μwatts/cm^2, R is the distance in centimetres, and S is power available from the UV source in μwatts.

The second attenuation mechanism relates to the absorptive properties of the medium through which the energy is transmitted. This is best described by Beer's Law:

$$I = I_0 \exp(-\alpha R) \tag{2-14}$$

where I_0 is the intensity at a given surface on the source (μwatts/cm^2), α is the absorbance coefficient of the medium through which the energy is passing (cm^{-1}), and R is the distance at which I is measured relative to the point represented by I_0. In the case of the low-pressure mercury arc lamps, the absorbance coefficient reflects the absorbance at the specific wavelength of 253.7 nm.

Combining **Equations 2-13** and **2-14** yields an expression which describes the intensity at a given distance from a single point source of energy:

$$I = [S/(4\pi R^2)] \exp(-\alpha R) \tag{2-15}$$

This equation serves as the basis for the point source summation calculation technique. A basic assumption is that a receiver (i.e., a microorganism) passing through the reactor is infinitely small and is spherical; by this it can then be presumed that the energy emitted from any point source element of the lamp will strike the receiver normal to its surface.

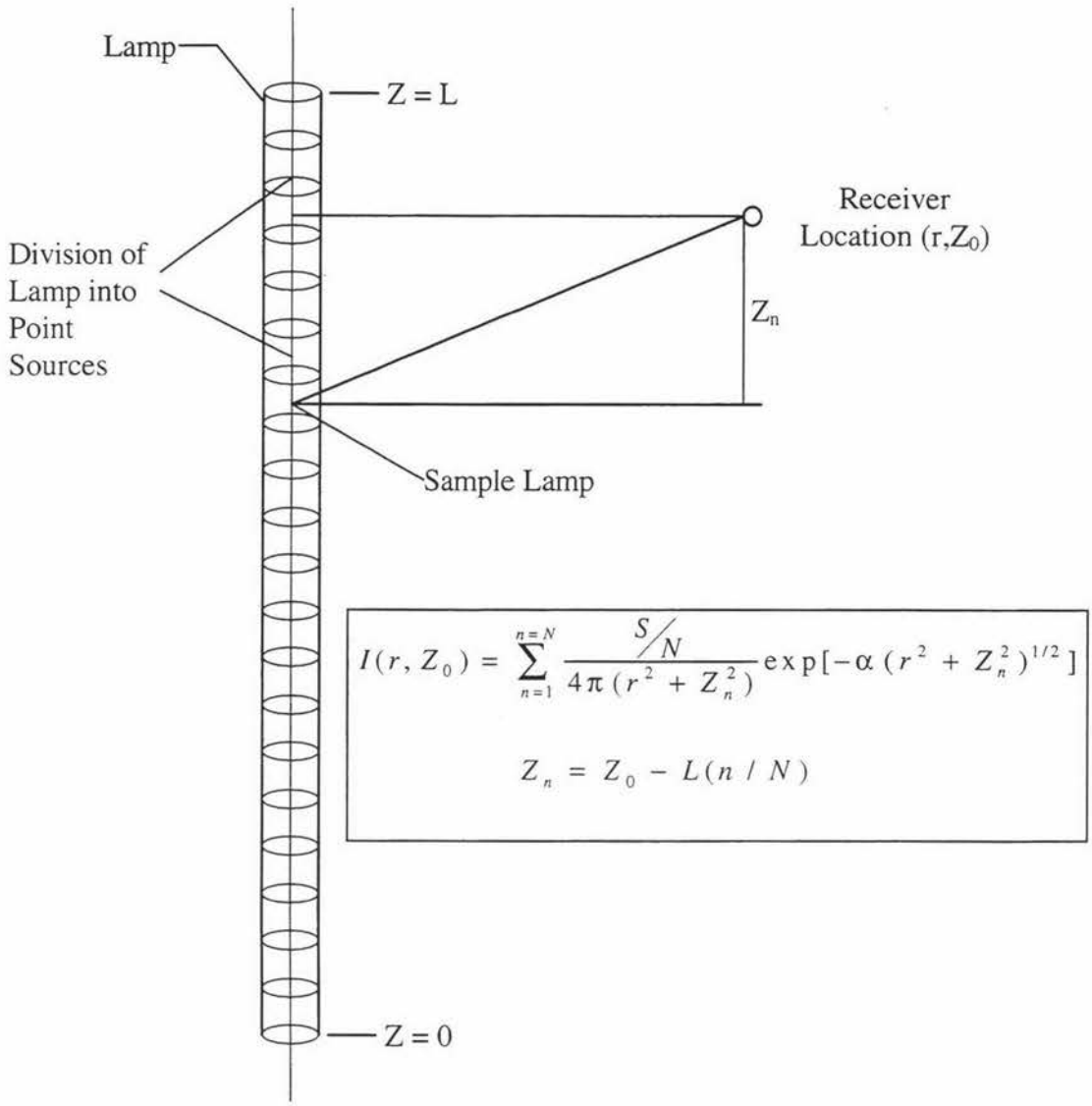

Figure 2-9 Lamp geometry for Point Source Summation (PSS) approximation of intensity (adapted from Stover *et al.*, 1986)

The model analysis also neglects the phenomena of reflection, refraction, diffusion, and diffraction of light and assumes that the absorptive properties of the liquid are independent of the light intensity. The intensity at the receiver is then the summation of the intensities from each of the point source elements of a lamp, (or lamps in a multilamp system). **Figure 2-9** is a schematic representation of this calculation. As shown, the intensity at the receiver location (r, z_0) is the summation of the intensities from each of the lamp elements:

$$I(r,z_0)=\sum_{n=1}^{n=N}\frac{S/N}{4\pi\left(r^2+z_n^2\right)}\exp[-\alpha\left(r^2+z_n^2\right)^{1/2}] \quad (2\text{-}16)$$

where N is the number of point source elements in the lamp. The value of z_n is:

$$z_n = z_0 - L(n/N) \quad (2\text{-}17)$$

Braunsein *et al.* (1996) assessed a field UV disinfection system and reported that for a 95% confidence interval, the PSS method resulted in an equivalent estimate of UV dose when compared with the bioassay method.

2.3.3.6 Predicting or modelling the reactor performance

Scheible (1987) presented a model for predicting UV process performance based on the nonideal reactor theory presented in many chemical engineering textbooks (Levenspiel, 1972). The governing equation for the model is as follows:

$$N = N_0 \exp\left[\frac{ux}{2E}\left\{1-\left(1+\frac{4E(aI_{avg}^{b})}{u^2}\right)1/2\right\}\right]+cSS^{m} \quad (2\text{-}18)$$

where

N	=	bacterial density after irradiation, cfu/100 mL;
N_0	=	bacterial density before irradiation, cfu/100 mL;
u	=	wastewater velocity, cm/s;
x	=	length of irradiated zone in the direction of flow, cm;
E	=	longitudinal dispersion coefficient, cm^2/s;
I_{avg}	=	spatially averaged UV intensity within the irradiated zone as estimated by PSS, mW/cm^2;
SS	=	effluent suspended solids concentration, mg/L; and
a,b,c,m	=	empirical coefficients.

The model is rationally based and comprehensive in that it follows conventional process theory and accounts for the factors that are known to affect UV process performance. Specifically, the model has incorporated terms that account for longitudinal dispersion, UV lamp output, and the presence of suspended solids (SS). As such, the model should be able to provide reasonable predictions of changes in process performance resulting from factors such as changes in hydraulic loading, lamp ageing, lamp fouling, or

variations in effluent SS. Experience with the model suggested the ability to predict effluent coliform density within approximately one order of magnitude (Scheible, 1987). The model has been successfully employed in the design of UV facilities (Gilbert and Scheible, 1993).

As stated by Bierck *et al.* (1996), a significant drawback to the application of the Scheible model is the need to determine representative values of four empirical coefficients (*a,b,c,* and *d*). The parameter a and b are used to relate the average intensity to the rate of microbial inactivation. The parameter c and m are used to relate SS to the concentration of viable, particle-associated microorganisms in the effluent. These coefficients can be determined experimentally but are site-specific.

Other models have been developed for predicting disinfection efficacy in flow-through systems. Emerick and Darby (1993) proposed an empirical model of the following form:

$$N = f\,(dose)^n \tag{2-19}$$

where

N	=	effluent coliform concentration. MPN/100 mL;
f	=	water quality factor;
dose	=	average UV dose, as estimated by PSS, mW·s/cm^2; and
n	=	empirical coefficient related to UV dose.

A hypothesis of this model is that inactivation can be predicted from a knowledge of UV dose and a measure of water quality (that is the water quality parameter *f*). An empirical relationship was postulated to describe the water quality factor:

$$f = A(SS)^a (T)^b (\beta)^c (N_0)^d \tag{2-20}$$

where

SS	=	suspended solids concentration, mg/L;
T	=	unfiltered transmittance at 254 nm, %;
β	=	particle size distribution coefficient;
N_0	=	influent coliform concentration, MPN/100 mL; and
A,a,b,c,d	=	empirical coefficients.

Multiple linear regression showed that UV transmittance (*T*) and suspended solids (*SS*) were the most important (Emerick and Darby, 1993). Though Emerick and Darby (1993) model predicted well for pilot data from two facilities, it will be applied at additional facilities in the future to assess its capabilities (Bierck *et al.*, 1996).

Severin *et al.* (1983 and 1984) developed a theoretical model for application to a completely mixed annular UV reactor. This model was verified by the authors on a reactor for which a complete assessment of hydrodynamic conditions (that is, complete mix) was available. Unfortunately, this model is of little use for the modular, open-channel systems used in the majority of disinfection operations because of the difference in the reactor geometry and mixing conditions. It is important to recognise that complete-mix conditions do not usually exist in the annular UV reactors (Severin *et al.*, 1984).

2.3.4 The Quality of Wastewater for Disinfection

As mentioned earlier, UV disinfection efficiency is affected by wastewater quality, which includes the particulates (in terms of suspended solids and turbidity) concentration, UV transmittance (or absorbance), and initial coliform density.

2.3.4.1 Suspended solids and turbidity

Bohm (1981) suggested that bacteria occluded in larger particles are more shielded from UV light than bacteria occluded in smaller particles. Qualls *et al.* (1983) found that the majority of shielded bacteria were embedded in particles larger than 10 μm. In other studies, it has been shown that coliforms harboured in larger particulates escape UV disinfection (Qualls *et al.*, 1983; Johnson and Qualls, 1984; Darby *et al.*, 1993). Because the occlusion of bacteria in the particulates will have a significant effect (**Figure 2-10**) on the design of a UV system, it is recommended by Stover *et al.* (1986) that the suspended solids measurement be used as the primary indicator to quantify the particulates. Darby *et al.* (1991) reported in a pilot study that UV disinfection achieved the

Californian limit of 2.2 total coliform per 100 mL on filtered secondary effluent but unable to comply the limit on unfiltered wastewater. When filtered secondary effluent was used as the feed to their system, they were able to meet the regulatory limit for coliforms; an unfiltered sample also achieved low coliform viability but was unable to comply with the limit. Bierck *et al.* (1996) stated that, in the case of municipal and biologically treated wastewater, the concentrations of suspended solids can be significant and account for essentially all residual coliforms in the final effluent after clarification. For this reason, a high degree of filtration is required, including, in some cases, chemical coagulation of colloidal solids, to achieve high disinfection efficiencies.

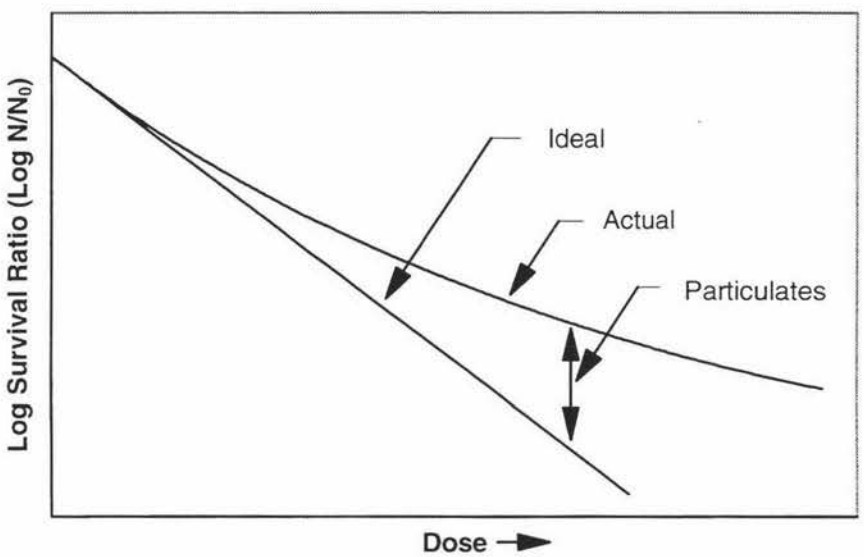

Figure2-10 Effect of particulates on UV disinfection efficiency

Scheible (1987) suggested a correlation with SS to predict the level of particulate coliforms after UV disinfection of treated municipal effluents:

$$N_p = c\,SS^m \tag{2-21}$$

Where

N_p = particulate coliform density, and

c,m = coefficients representing intercept and slope, respectively, of a log-log regression analysis of SS data, with the effluent coliforms measured after imposition of high UV dose.

Ellis (1991) reported that turbidity in water undergoing disinfection is not a factor of major concern in most modern water treatment works. These are designed and operated, to a large extent, to remove such turbidity and to produce a water which is sparkling and clear. However, small installations, with which the filtration stage may either be of lower efficiency or occasionally nonexistent, turbidity at the time of disinfection is a factor that must be considered. Turbidity must be removed before disinfection by UV radiation to improve light transmission. **Section 2.3.4.4** presents detailed water quality requirement for turbidity and suspended solids.

2.3.4.2 UV transmittance

The one parameter which is solely in the venue of UV disinfection is the UV "demand" of the wastewater. Specific organic and inorganic compounds in the wastewater will absorb and scatter energy at the 253.7 nm wavelength. This absorbance will affect the intensity of the radiation within the reactor; in specific design situations, the level of absorbance will affect the sizing of a system and possibly the configuration (spacing) of the lamps. Recall that the average nominal intensity is a function of the absorbance coefficient.

The transmittance of the wastewater is a common parameter used to describe the "demand" of the wastewater. This can be determined from the absorbance measurement, and is most often expressed on a percent basis:

$$\% \, Transmittance = 100 \times 10^{-(a.u./cm)} \tag{2-22}$$

Conversely, the percent absorbed is simply 100 percent minus the percent transmittance. The approximate value of absorption coefficient α of UV radiation in water had been derived by Sobotka (1993) as:

$$\alpha = 0.0163T + 0.0051c + 0.0514 \tag{2-23}$$

where:

α = absorption coefficient in cm^{-1}.
T = turbidity in mg-SiO_2/l;
c = colour in mg-Pt/l;

According to Sobotka (1993) the above formula can be used in designing devices and calculating the efficiency of the bactericidal effect.

The single beam, spectrophotometric method for measuring the UV absorbance of the liquid is the simplest procedure, requiring minimum effort and instrumentation. It is important to note however, that this "direct" UV absorbance measurement assumes that light which does not pass through the cell and is not seen by the detector has been absorbed by the liquid. This is not necessarily the case, especially in samples which have suspended and colloidal particles in the liquid. These will cause a portion of the light to be scattered; the light is still available, but it will not be seen by the detector since it has been deflected from its direct path through the quartz cell. Thus, the direct method tends to overestimate the "true" absorbance of the liquid.

Johnson and Qualls (1984) demonstrated that suspended or colloidal particles will not absorb any significant amount of light energy and will in fact scatter the light back to the liquid. Scheible *et al.* (1986) resulted the same conclusion. It becomes important, therefore, that the absorbance measurement must in some fashion account for the scattering effect and give a value representative of the true absorbance of the liquid (Stover *et al.*, 1986).

Stover *et al.* (1986) reported that a sphere, a standard accessory to the UV/Visible spectrophotometer would correct the absorbance measurement for the effect of scattering. The absorbance, referred to by the Port Richmond report (Scheible *et al.*, 1983) as the "spherical" absorbance coefficient, is felt to be more closely represent the true absorbance of the liquid (Stover *et al.*, 1986).

It is recommended by Stover *et al.* (1986) that, in the case where the capability to measure the corrected UV absorbance coefficient is not available, the UV absorbance coefficient should, at minimum, be determined on filtered samples by the direct method. The results would be further improved if this is accomplished by membrane filtration to remove particles greater than 1 micron in size. Care should be taken to prewash the filters; in some instances the filter matter itself can contribute UV absorbing materials (Stover *et al.*, 1986).

2.3.4.3 Other wastewater quality parameters

As reported by Severin *et al.* (1983), UV disinfection is relatively insensitive to temperature changes. Abu-ghararah (1994) also found that there was no statistically significant difference in activation kinetics over the temperature range of 20 - 40°C. Reported rate constants for faecal coliform inactivation were 350, 590, and 770 $cm^2/\mu W \bullet s$ for temperatures of 10, 20-40, and 45°C, respectively.

The initial coliform density of the wastewater is critical in the case of disinfection by UV, as it determines the log survival ratio, N/N_0, required. The initial coliform density affects the UV dose requirement, and is site specific and varies from time to time in a wastewater treatment plant.

High particle iron concentrations (resulted from $FeCl_3$ coagulation in upstream treatment) decreased coliform inactivation by UV irradiation (Gehr *et al.*, 1993).

2.3.4.4 Water quality requirements for effective UV disinfection

Though Stover *et al.* (1986) did not provide guidelines for UV transmittance required for effective disinfection, these authors mentioned that UV process should be applied for secondary and tertiary (municipal) effluent. The UV transmittance for secondary and tertiary effluent was 60 to 74% and 67 to 82% respectively. This corresponds to UV absorbances of 0.22 to 0.13 and 0.174 to 0.087.

Bierck *et al.* (1996) reported that, typically, the UV transmittance of secondary effluents would be greater than 60% on a filtered basis, although lower values, on the order of 50%, have been observed. The filtered measurement presents a more representative estimate of the transmissibility through the effluent water and is critical to the design sizing of the UV system.

In some cases, particularly at low transmittance levels, it may be necessary to reduce the spacing of the lamps or consider using advanced higher intensity systems to overcome

the lower transmissibility of the water. This is generally the case at transmittance levels of less than 50% (Bierck *et al.*, 1996).

Shama (1992) developed a special UV irradiation apparatus, known as "liquid bells", to disinfect an artificial wastewater (i.e., humic acid solution) with high UV absorptivities (0.18 to 4.0 at 254 nm). Because the liquid film generated was as thin as 1 to 0.15 mm, survival ratio between 1.88×10^{-5} and 1.84×10^{-4} was achieved after 30 minutes of irradiation.

Stover *et al.* (1986) summarised the characteristics of secondary and tertiary domestic effluent for UV disinfection as follows: suspended solids 2.6 to 33.2 mg/l, turbidity 1.2 to 8.6 NTU, COD 14.6 to 92.0 mg/l, and UV absorbance 0.113 to 0.333 abs/cm which corresponds to UV transmittance of 77 to 46.5%/cm. Other published data concerning the water quality requirements for effective UV disinfection are summarised in **Table 2-3**.

Table 2-3 Water quality parameter values reported for effective UV disinfection

Wastewater Source	Total SS (mg/l)	Turbidity (NTU)	UV Transmittance (%/cm @ 254 nm)	Reference
secondary	2.7 - 10.9	1.30 - 3.95	60.9 - 73.9	Parker *et al.*, 1995
secondary	7 - 32	n.d.	49 - 65	Job *et al.*, 1995
secondary	5 - 50	0.5 - 12	n.d.	Petrasek *et al.*, 1980
secondary	1.3 - 7.0	1.1 - 3.8	73.6 - 78.0	Darby *et al.*, 1993
FASE*	1.18 - 2.4	0.6 - 2.4	65.3 - 86.8	Braunstein *et al.*,1996
secondary	n.d.	1.5 - 10.0	60 - 83	Blatchley *et al.*, 1996

* Filtered Activated Sludge Effluent; n.d.= no data.
Reported as range of values.

The Instruction Manual for the UV disinfection system Model LC50 (Ultraviolet Technologies New Zealand, 1995) listed the following water quality criteria:

	Potable Water	**Effluent**
UV transmittance @ 254 nm:	≥ 82%/cm	≥ 65%/cm
Colour:	< 2 T.C.U	< 20 T.C.U
Turbidity:	< 1 NTU	no recommendation
Non filterable residual:	no recommendation	< 20 mg/l
BOD_5	no recommendation	< 20 mg/l
Iron:	<0.5 mg/l	<0.5 mg/l

Though there was no unanimous wastewater quality standard for effective UV disinfection, most literature reported turbidity levels of less than 10 NTU, and UV transmittance levels of greater than 60%/cm.

2.4 GENERAL CONSIDERATIONS IN ADOPTING UV DISINFECTION

2.4.1 Advantages and Disadvantages of UV Disinfection of Wastewater

Overall, the advantages of UV disinfection can be listed as (Ellis, 1991)

- Satisfactory disinfection (Both bacteria and viruses inactivated);
- No alteration to the chemical composition of the water;
- No addition of taste and odour;
- No production of potentially harmful chemicals;
- No induced aftergrowth as a result of the partial breakdown of large organic molecules;
- Low installation and operational costs;
- Low maintenance requirements;
- No danger from overdosing;
- No chemical handling;
- Limited space requirements;
- Few corrosion problems;
- Ease of automation;
- Limited contact time hence no reaction tank required, and
- Ease of operation.

Wolfe (1990) listed the following disadvantages of UV disinfection of potable waters;

- Limited information on factors influencing effectiveness in the field; limited experience with UV technology;
- No residual provided for disinfection in the distribution system; post disinfectant needed

for surface waters;

- Uncertainties regarding accuracy and reliability in measuring UV dose (current systems rely on sensors and theoretical measurements), and
- Technological limitations on practical size (up to approximately 20 mgd) of treatment plants that can be cost-effectively disinfected by UV.

Blatchley *et al.* (1996) reported that lamp jacket fouling was the major limitations to performance in the UV system, however, it could be controlled by air sparging effectively. No literature mentioned other drawbacks of UV disinfection of wastewaters. As reported by Bierck *et al.* (1996), experience is gaining and improvements in UV technology have made UV disinfection a preferred choice for wastewater disinfection (see Section 2-1). No residual disinfectant is actually an advantage for wastewater treatment. Some microorganisms, especially giardia cysts, are resistant to UV and require much higher dose for disinfection. Gadgil (1995) suggested the use of flocculating agent (e.g., alum) to remove giardia spores. However, he believed that the simplest way was to couple a UV disinfection unit with a sand filter. Other possible disadvantages such as high wastewater quality requirement, lamp fouling are being overcome with the technological advances in UV disinfection.

2.4.2 Economics of UV Disinfection

Formally chlorine-based disinfection was the cheapest process. Dechlorination and containment facility requirements have increased its cost. At the same time, the development and application of open-channel, modular systems have reduced the cost of UV disinfection. Consequently, the costs of the two processes are comparable for new facilities (Putnam *et al.*, 1993).

2.4.3 System Design

At present, UV system design relies on a combination of past experience, pilot testing, and numerical modelling. Each factor is related, and the degree to which each is used often depends on the size of the system being considered, the budget, and the schedule (Bierck *et al.*, 1996). Smaller system design can be based on the expected wastewater characteristics and the conventional practices. For the design of medium to large facilities, capital and operating costs can be substantial; in such cases, it is important to

base the design sizing on relevant and site-specific wastewater characteristics. Pilot testing is recommended, particularly if advanced, nonconventional UV systems are being considered (Bierck *et al.*, 1996).

Final design of a full-scale UV system will include establishing the number of lamps required to meet disinfection requirements under design conditions. Equally critical is the manner in which they are configured in the full-scale design. It is preferable to design the system with relatively long, narrow channels to encourage plug flow and avoid any degree of short-circuiting. A screening guideline was provided by U.S.EPA (1992).

Hydraulic design is one of the more critical factors to consider when laying out the full-scale system. Bierck *et al.* (1996) discussed factors to be considered when designing the channel and its related structures. These included the selection of proper inlet and outlet structures, consideration of multichannel configurations, wastewater level stabilisation facilities, system control, safety and protection of the system and personnel, and matters concerning the maintenance of the system.

Bierck *et al.*, (1996) reported that many WWTPs are abandoning chlorination and switching to UV disinfection. Existing chlorine contact chambers offer an opportunity to cost-effectively install the equipment. The most significant hydraulic constraint often encountered in retrofit applications is the available head.

2.5 FARM DAIRY EFFLUENT QUALITY FOR UV DISINFECTION

Generally speaking, pond treated farm dairy wastewater has poorer quality compared to pond treated municipal effluents. Hickey *et al.*, (1989a and 1989b) examined the characteristics of both domestic and dairy shed wastewaters in New Zealand. The main characteristics of these wastewaters relevant to UV disinfection were summarised in **Table 2-4**.

From the results of Hickey *et al.* (1989a and 1989b), it can be seen that the BOD and SS concentration are more than 3 times higher in dairy shed pond effluent than in domestic

pond effluent. The coliform concentration in dairy shed effluent was almost 100% higher than that in domestic wastewaters. Another contrasting data is that while most of the coliforms in dairy shed effluent were faecal, only one-tenth of the coliform in domestic wastewater was faecal.

Table 2-4. Summery of effluent characteristics for domestic sewage oxidation ponds and dairy shed oxidation ponds (adopted from Hickey *et al.*, 1989a and 1989b)

Variables (units)	Domestic Median	Dairy Shed Median
Temperature (°C)	16	13.1
Conductivity (mS/m)	42.2	180
pH	8.1	7.9
DO (mg/l)	8	2.8
BOD (mg/l)	27	98
SS (mg/l)	56	198
Turbidity (NTU)	28	no data
Secchi depth (cm)	20	no data
***Coli* (100 mL)$^{-1}$**	43 000	80 000
F. *Coli* (100 mL)$^{-1}$	4 300	70 000

Mason (1994), Bolan *et al.* (1996) and Flowerday (1997) monitored one farm dairy pond effluent independently. The COD values in their reports were 884, 615, and 837 mg/l respectively, and the suspended solids concentration was 364, 185, and 297 respectively.

According to Li (1997) the turbidity level in (Massey No. 4) dairy shed pond effluent varied between 360 to 630 NTU from winter to early summer. This is more than 10 times higher than the data reported by Hickey *et al.* (1989a) for domestic wastewater. More importantly, according to previous work by Flowerday (1997), UV transmittance (through 1 cm quartz cell) at 254 nm was zero. Flowerday (1997) used filtration and centrifugation for the treatment of wastewater and achieved less than 2%/cm transmittance at 254 nm. He did not characterise the material in the wastewater and suggested further research, including the removal of UV absorbing materials for the disinfection of farm dairy wastewater by UV.

2.6 SUMMARY OF LITERATURE REVIEW

The gemicidal effect of UV radiation in sunlight was first discovered by Downes and Blunt in 1877, and in 1901 Hewitt developed a mercury vapour arc lamp for the effective production of UV radiation. UV disinfection of water was first applied by Cernovodeau and Henri in 1910. The emergence of UV radiation as an important wastewater disinfection alternative may be attributed to the drawbacks of conventional chlorination, improvements in UV technology, and advances in the understanding of the UV.

UV disinfection is a physical process. UV radiation over the range $240 < \lambda < 260$ nm is microcidal. Though the most effective spectral region for germicidal activity lies about 260 nm, UV radiation at 253.7 nm was used predominantly because of the prevalence of the low pressure mercury arc lamp systems which concentrate 85% of their output at the wavelength of 253.7 nm.

It is believed that the majority of UV-induced damage is imposed on the bases that compose nucleic acods. Dimerization of adjacent bases (especially thymine) on nucleic acid strands has been identified as the predominant UV inactivation mechanism.

Photoreactivation is a process whereby dimers within microbial mucleic acids are catalytically repaired to their original monomeric forms. Dark repair involves enzymatic recognition of a dimer on a DNA strand. One design approach regarding the inclusion of recovery mechanisms has been the increased level of UV dose.

The UV dose required for effective disinfection is a function of the sensitivity of the microorganism to UV, UV irradiation intensity, exposure duration. Viruses and bacteria are inactivated effectively by UV radiation, whereas protozoa cysts and spore-forming bacteria are relatively resistant to inactivation. Though reported exposure durations for UV disinfection vary, the detention time typical for UV systems is less than 10 seconds.

The modular, open-channel UV system using a conventional low-pressure mercury arc lamp is currently the industry standard. Though lamp life has increased up to 14,000

hours, operating life of 7,500 to 8,000 hours has been recommended by U.S.EPA for mercury arc lamps. Lamp jacket fouling was formerly a problem for UV disinfection systems, but technological advances are providing solutions to mitigate.

The average UV intensity in a reactor can be estimated by point source summation (PSS) method or bioassay method and the performance of UV reactors can be modelled or predicted by models.

Wastewater quality affects UV disinfection. Suspended solids shield bacteria from UV light thus limited the efficacy of UV disinfection. Turbidity must be removed to a certain level to improve light transmission. A high degree of filtration is required, including, in some cases, chemical coagulation of colloidal solids, to achieve high disinfection efficiencies.

In case of lacking of accurate UV absorbance measurement instruments to account for the effect of scattering, Stover *et al.* (1986) suggested the use of filtered samples for absorbance and transmittance measurement. UV transmittance of 60%/cm may be the minimum requirement for effective disinfection.

No information was found on the application of UV disinfection to farm dairy wastewater. In terms of UV disinfection, the quality of farm dairy effluent is generally poorer than that of the domestic wastewaters. The nature of the material limiting UV penetration has not been characterised. Further study is recommended, including the removal of UV absorbing materials.

2.7 JUSTIFICATION AND OBJECTIVES OF THIS STUDY

To acquire information on UV disinfection of farm dairy wastewaters, experimental study will be carried out to investigate the nature of the waste material, and the possibilities of improving the optical quality to achieve better UV penetration for effective disinfection. The specific objectives of this study are:

- To provide further information of the characteristics of pond-treated farm dairy wastewaters;
- To investigate treatment technologies for the improvement of wastewater optical quality, including dilution, filtration, chemical coagulation, centrifugation, oxidation, adsorption treatment.

CHAPTER THREE
MATERIALS AND METHODS

3.0 INTRODUCTION

Chapter 2 identified the major problem with the application of UV radiation for farm dairy wastewater disinfection as the poor optical quality of the wastewaters, due to the high turbidity, suspended solids and high UV absorbance by the dissolved matter in the wastewater. To apply UV disinfection technology to farm dairy wastewater effectively, the nature of the waste material must be characterised and UV transmittance through the wastewater must be increased. This chapter describes the sampling, analysis and treatment of farm dairy wastewaters aimed to investigate wastewater characteristics and to improve their optical quality.

3.1 SOURCES OF FARM DAIRY WASTEWATER

Wastewater samples were collected from Massey No. 4 Dairy Farm and six other dairy farms. Their wastewater generation and treatment systems are briefly described in the following two sub-sections.

3.1.1 Massey No. 4 Dairy Farm

Established in 1973, the Massey No. 4 Dairy Farm is situated 3 km south of the city of Palmerston North. Its total area is 206 ha with flat to undulating contours. The overall elevation is 80 metres above sea level. The farm is on factory supply with milking season (lactation) of 250 days starting in September. Besides operating on commercial basis, the farm provides facilities for teaching and research associated with seasonal dairying. Stock numbers are now stable at around 500 cows. Each day, 25,000 litres of water (estimated @50 litres per cow per day, Heatley, 1995) is used for yard and plant washdown. A concrete feedpad (170 cows) at the cowshed is used regularly in winter. Runoff from yard and feedpad goes to the pond system too.

The current two-pond system was built in 1978 following the breakdown of a sprinkler (honey pot) system which suffered from managerial and physical problems associated with its operation, such as anaerobic soil conditions, weed growth, sump overflow, pump and sprinkler breakdown. The treatment performance of the two-pond system was studied by many researchers and students, including the general monitoring by Mason (1994) and Bolan *et al.* (1996). Maintenance was carried out regularly and the two pond system achieved an adequate removal of the suspended solids, COD and BOD (Bolan *et al.*, 1996). The farm was granted discharge permit (right number 912284) from the Manawatu - Wanganui Regional Council on 16 July, 1991. Though the conditions in the discharge permit (no more than 625 g/hour BOD_5 and 835 g/hour suspended solids) were met, the farm has received warn from the Regional Council that the pond effluent was not complying with the discharge standard, especially colour and nutrients.

3.1.2 Other Dairy Farms

A list of names and numbers of dairy farms in the vicinity of Palmerston North, Linton, Levin area was obtained from the Environmental Monitoring Officer of the Manawatu - Wanganui Regional Council. Telephone calls to the farm owners were made one week before the planned sampling date. Six of these farmers agreed to have their effluent sampled on the agreement that their names and details of effluent quality results will not be exposed to any other party for any purpose. So in this study, the exact name and location of the farm were suppressed to protect the interest of these farmers. Instead the alphabetical code names were used to identify different farms. However, a general description of their wastewater treatment systems is given below.

Farm A: The wastewater treatment system in Farm A was a typical two-pond system. All the wastewater flow is by gravity. Effluent from the second pond discharged into an unnamed stream with very small dilution capacity. Design, management and maintenance of the system was excellent.

Farm B: The wastewater treatment system in Farm B was a special pond system. There were three ponds in the treatment system. However, according to the farmer, effluent

from the farm dairy was diverted directly into the second pond and then passed into the third pond via a plastic pipe. The purpose of the first pond was collecting runoff from the adjacent land and diverting it into the second pond. All the wastewater flow was by gravity. Final discharge of the treated wastewater was to an unnamed stream with very low baseflow. Visually, effluent from the pond system had a very good clarity.

Farm C: The wastewater treatment system in Farm C was a typical two-pond system. All the wastewater flow was by gravity. Effluent from the second pond discharged into an unnamed stream with a substantial dilution capacity. A small dam upstream collected runoff and provided baseflow for the stream. Design, management and maintenance of the system was excellent.

Farm D: The wastewater treatment system in Farm D was a two-pond system. All the wastewater flow was by gravity. Effluent from the second pond discharged into an unnamed stream with no dilution capacity, except immediately after heavy rainfall. At the time of sampling, the first pond was filled with sludge and there was no room to store more yard washdown. Wastewater passed through to the second pond in such a short time that no substantial retention time was provided by the first pond.

Farm E: The wastewater treatment system in Farm E was a two-pond system. All the wastewater flow was by gravity. Effluent from the second pond discharged into an unnamed stream with a substantial dilution capacity. There was no control structure on the wastewater passway. Effluent from the first pond went to the second pond via a crack in the middle of the dividing dike. Similarly, effluent from the second pond went to the receiving stream through a breach on the corner of the pond. The management of the wastewater treatment system was so bad that the two ponds were completely filled with sludge and there was no visible liquid storage capacity in the two ponds.

Farm F: The wastewater treatment system in Farm E was a pond-barrier ditch system. Effluent from the anaerobic pond flowed into the barrier ditch system, which consisted 3 ditches in sequence, each measuring 50 metres in length and 2 metres wide. All the

wastewater diversion was by gravity and through 4-inch plastic pipe. Effluent from the last ditch discharged into an unnamed stream with considerable dilution capacity.

One thing in general to all these six farms were that all the treatment systems were fenced, some were excluded from stock permanently. The other thing which was common was that herd sizes had increased substantially over the last couple of years. In fact, some farmers had started worrying about whether they would be able to get their discharge permit renewed with the current treatment system, with an increased herd size. No farmer had a plan to put effluent onto land. Many of them knew neither the capacity nor the dimensions of their treatment system.

3.2 SAMPLING OF FARM DAIRY WASTEWATER

3.2.1 Massey No. 4 Dairy Farm

Wastewater samples were taken monthly between 9 and 10 am from 17 July 1997 to 18 December 1997. All samples were collected from the discharge pipe (which draws effluent from a depth of approximately 0.2 m) outlet, using 2-litre plastic bottles. These plastic bottles were cleaned and stored in the dark in the laboratory and rinsed twice with wastewater before collecting the samples. Sample temperature and electrical conductivity were measured on site. Wastewater samples were not chilled during transport because the transportation time was less than ten minutes. Upon reaching the laboratory on the Turitea Campus wastewater samples were analysed immediately. A portion of the samples were put into refrigerator and stored at 4°C for later use.

3.2.2 Other Dairy Farms

Wastewater samples from farm dairies were taken between 9 and 11 am on 21 October 1997. Most samples were collected from the discharge pipe outlet. Samples from Farm E were collected from a puddle on the bottom of the breach draining the second pond (there was no control structure in Farm E). The 2-litre plastic bottles were cleaned and stored in dark in the laboratory and rinsed twice with wastewater before collecting the

samples (except for Farm E which offered no spare volume for rinsing the bottle). Wastewater samples were not chilled during transport because the transportation time was less than 3 hours. Upon reaching the laboratory samples were analysed immediately. A portion of the samples were put into refrigerator and stored at 4°C for possible later use.

3.3 ANALYSIS OF FARM DAIRY WASTEWATER

Except for the temperature and electrical conductivity (EC) measurement, all wastewater quality parameters were measured at room temperature (18-20°C).

3.3.1 Temperature

Temperature was measured using a portable YSI 30 Salinity, Conductivity and Temperature Meter on site or a mercury thermometer in the laboratory. In both cases, an accuracy level of 0.1°C was employed. In the case of measuring temperature using the YSI 30 metre, procedures outlined in the instrument manual (Yellow Springs Instrument Co. Inc., Ohio, 45387-0279, USA ,1991) were followed.

3.3.2 pH

The measurement of pH value was conducted using a PHM80 Portable pH Meter (Radiometer Pacific Ltd, Penrose, Auckland, New Zealand). Due to the fragility of the electrode, pH measurement was only carried out on the bench in the laboratory. The instrument was calibrated regularly, especially before each experiment, with two standard buffer solutions (pH = 4.0 and pH = 7) provided with the instrument. All the calibration and measurement were practised according to the instrument manual.

3.3.3 Electrical Conductivity (EC)

Electrical conductivity of the wastewaters was measured using a portable YSI 30 Salinity, Conductivity and Temperature Meter (Yellow Springs Instrument Co. Inc., Ohio, 45387-0279, USA). Regular maintenance was practised on this instrument. Calibration was carried out with standard potassium chloride solution (Standard Methods, 1995).

3.3.4 Turbidity

Turbidity measurement was carried out in the laboratory using the Nephelometric Method described in Standard Methods (Standard Methods, 1995), on a HACH 2100 P Portable Turbidimeter (HACH Company, P.O. Box 389, Loveland, CO 80539-9986, USA). Regular maintenance was practised. Calibration of the instrument was carried out before each set of experiment using the three standards (0 -10, 10 - 100, and 100 - 1000 NTU) supplied with it. Turbidity was measured at room temperature to remove fog formation. Interferences were removed by methods recommended in Standard Methods (1995).

3.3.5 Suspended Solids (SS)

The total suspended solids content of wastewaters was measured with Whatman GF/C glass-fibre filters (Whatman International Ltd., Maidstone, England), following the procedures outlined in Standard Methods (1995). The 7-cm GF/C filters were pre-rinsed with distilled water and dried at 103-105°C for one hour and balanced in desiccator and weighed before use. Sample sizes were carefully selected to yield between 10 and 200 mg dried residue. A high-sensitivity balance (0.0001 g) was used for weighing the filters. Samples were measured in triplicate.

3.3.6 Biological Oxygen Demand (BOD)

In this study total BOD was measured, using a respirometric method. Two sets of HACH 2173A BOD apparatus (HACH Company, P.O. Box 389, Loveland, CO 80539-9986, USA) were used. The BOD bottles were 500 ml brown glass bottles. A sample

size of 157 ml was chosen for all the wastewater samples including those treated. In case of those samples filtered through 0.45 μm filter paper, seeding was carried out using raw effluent from the No. 4 pond outlet. The amount of BOD contributed by the seed source was deducted from the BOD results. Duplicates were used for all the BOD test samples.

3.3.7 Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) of the samples was determined by the Closed Reflux, Colourimetric Method (Standard Methods, 1995). Standard 10 ml culture tubes and two sets of HACH COD heater blocks (HACH Company, P.O. Box 389, Loveland, CO 80539-9986, USA) were used for all the tests. A Philips PU8525 UV/VIS Spectrophotometer (Philips Analytical, York Street, Cambridge, Great Britain, CB1 2PX) at 600 nm was used for absorbance measurement of digested COD samples. Five blank and five potassium hydrogen phthalate standard were run for each set of COD test. Triplicates were used for all the COD test samples. COD values reported were the arithmetic means calculated from these triplicates.

3.3.8 UV Transmittance and UV Absorbance

The UV transmittance and/or absorbance of wastewaters was measured at 254 nm using a Philips PU 8625 UV/VIS (single beam) Spectrophotometer (Philips Analytical, York Street, Cambridge, Great Britain, CB1 2PX). Generally, this was carried out using a 1 cm quartz cell. The spectrophotometer was turned on and its wavelength adjusted to the required value and stabilised for 30 minutes. The instrument was calibrated at 100% transmittance or 0 absorbance using a quartz cell (1 cm path length) containing deionized water. The quartz cell was rinsed twice with the sample, then the sample was placed in the quartz cell and transmittance or absorbance was recorded. In the case of strong wastewater samples with extremely low transmittance or extremely high absorbance, either a 1 mm quartz cell was used, or those samples were diluted by a factor of 10 prior to measurement. However, results were always converted to that of a 1 cm cell with no dilution and reported as such.

3.3.9 Absorbance Spectra

The absorbance spectra of wastewater samples were determined on a Shimadzu UV-160A UV-VIS Recording spectrophotometer with 1 cm quartz cells. All the sample preparation and instrument operation procedures were carried out according to the Instruction Manual (Shimadzu Corporation , Analytical Instruments Division, Kyoto, Japan).

3.4 TREATMENT OF FARM DAIRY WASTEWATER

Wastewater samples were first brought to room temperature before being treated. Duplicate samples were used for all treatments. Blanks or controls were run to exclude the influences of factors other than those tested.

3.4.1 Filtration

Both raw and treated farm dairy wastewaters were filtered through 1.2 micron (GF/C) filter paper, 0.45 micron filter paper, and 0.22 micron filter paper (Whatman International Ltd., Maidstone, England). To quicken the filtration process, raw wastewater was first filtered through 20-25 micron laboratory filter papers (Whatman, no. 41) before filtered through 1.2 micron filters. Filtrates from these processes were taken for analysis.

3.4.2 Dilution

Dilution was carried out using 50 mL volumetric flasks and distilled water. Both raw and treated wastewater samples were diluted into 0.5, 0.2, 0.1, 0.05, and 0.01 using serial dilution techniques.

3.4.3 Coagulation

Farm dairy wastewater samples were coagulated with aluminium sulphate solution on a bench scale basis. Wastewater samples were brought to room temperature and then 100 mL of these samples were put into 120 mL plastic cups and the cup was placed on a magnetic stirrer. A magnetic flea was dropped into the cup and the stirrer was started and the speed of it was adjusted to and maintained at medium (about 200 rpm). Aluminium sulphate solution was added into the cup using a micro-pipettor and the solution was stirred for 2 minutes. The sample cup was removed from the stirrer and the flocs in it were allowed to settle. After 2 hours, supernatant was taken from each cup from 1 cm below the liquid surface and filtered through 0.45 micron filter paper. Both the filtered and unfiltered samples were analysed. Varied lengths of stirring and settling time were used to check the effect of them on coagulation efficiency (see Chapter 4 for details).

Experiments were carried out to compare the effectiveness of zinc sulphate and aluminium sulphate in coagulating the wastewater. 1 mL of 100 g/l zinc sulphate ($ZnSO_4$•7H2O) solution was used to coagulate 100 ml of raw farm dairy wastewater. Similarly, 1 ml of 77.3 g/l aluminium sulphate solution ($Al_2(SO_4)_3$•$18H_2O$) was used to coagulate 100 ml of raw wastewater. These treatment gave 0.007 N/L of either Zn^{2+} or Al^{3+} cation dosage. The pH was adjusted to the optimum value (determined through experiment, 10.5 for zinc sulphate treatment and 4.5 for aluminium sulphate treatment).

The stock solutions of aluminium sulphate, 200 g/L (or 16.21 g-Al/L) were prepared fresh monthly, using deionized water and crystalline form analytical reagent grade $Al_2(SO_4)_3$•$18H_2O$ (BDH Laboratory Supplies, Poole, BH15 1TD, England), and kept in a cool and dark place. The stock solution of zinc sulphate, 100 g/L (or 22.7 g-Zn/L) was prepared once, using deionized water and analytical reagent grade $ZnSO_4$•$7H_2O$ (BDH Chemicals Ltd, Poole, England) and kept in a cool and dark place.

3.3.4 Centrifugation

A Sorvall Ultracentrifuge (Model OTD75B, Doupont Company, Biomedical Products, Sorvall® Instruments, Wilmington, Delaware 19898, USA) was used. Samples of coagulated and filtered (0.45 μm) wastewater were centrifuged at 10,500 g for 1 hour and then supernatants were taken from the centrifuge bottles using glass micro-pipettors for analysis.

3.4.5 Adsorption

Both raw and treated farm dairy wastewater samples were treated with activated carbon (AC), zeolite and two classes of bark (composted *Pinus radiata*, Bark A = coarse and bark B = fine). Each 100 mL of wastewater sample was put into 120 mL plastic cup. A dose of adsorbing reagent was added into each cup and the solution was stirred at medium speed on a magnetic stirrer for a period of time (5 minutes to 5 days; see Chapter 4 for details about stirring duration for different adsorption treatment). The cup was removed from the stirrer and the particulates in it were allowed to settle. Supernatant was taken from each cup and filtered through 0.45 micron filter paper.

The activated carbon reagent was a powder form of charcoal produced by BDH Laboratory Supplies, Poole, BH15 1TD, England.

The zeolite and bark reagents were provided by Dr. N.S. Bolan in the Department of Soil Science of Massey University. The average particle size was 8 mm for bark A and 4 mm for Bark B. The cation exchange capacity (CEC) of both barks was around 100 cmol/kg. The zeolite used was a powder form hydrated aluminium-silicate mineral with more than 95% in the particle size range of 0.063 - 0.5 mm.

3.4.6 Oxidation

Treated (coagulated by 1600 mg/l aluminium sulphate and filtered through 0.45 micron filter paper) farm dairy wastewater samples were treated with hydrogen peroxide

solution. Wastewater samples were treated by different hydrogen peroxide doses and reaction durations (see Chapter 4 for details). Hydrogen peroxide solution was dosed into plastic cups containing 100 mL wastewater sample, and the content was stirred at a moderate speed of about 200 rpm continuously. Samples were filtered through 0.45 micron filter prior to optical analysis.

The hydrogen peroxide reagent contained 50 g of H_2O_2 per 100 mL (determined by the method outlined in Scott (1939).

3.5 ANALYSIS OF EXPERIMENTAL DATA

Both spreadsheet (Microsoft Excel 5.0) and the SAS System were employed for the analysis of the experimental data. The QBASIC programme was used for the calculation of BOD coefficients. The Fujimoto Method was used for the calculation of BOD constants (Metcalf & Eddy, 1991). Statistical analysis (Anova, Duncan) was used to determine the differences between treatment efficiency and relationships among wastewater parameters.

CHAPTER FOUR

RESULTS

4.0 INTRODUCTION

This chapter presents the results from monitoring and treatment of pond treated farm dairy wastewaters.

4.1 CHARACTERISTICS OF FARM DAIRY WASTEWATERS

4.1.1 Wastewater from Massey No. 4 Dairy Farm

Six wastewater samples were collected and analysed in the testing season. The general wastewater characteristics of these samples are summarised in **Table 4-1**.

Table 4-1 Characteristics of pond treated wastewater from Massey No. 4 Dairy Farm

Parameter	Mean	Standard Deviation	Range	No. of Tests
Temperature (°C)	12.9	4.2	7.1 - 18.3	6
EC (µS/cm)	2374	229	2049 - 2750	6
SS (mg/l)	317	131	133 - 489	6
Turbidity (NTU)	450	142	181 - 546	6
COD (mg/l)	809	201	478 - 943	6
BOD_5 (mg/l)	150	9.85	139-158	3
UV Transmittance (%)	0.0	n.m.	0.0-0.0	6

where: EC = Electrical Conductivity, SS = Suspended Solids, COD = Chemical Oxygen Demand, and BOD_5 = 5 day Biochemical Oxygen Demand; n.m. = not measured.

Table 4-1 shows that wastewater quality parameters such as temperature, turbidity, suspended solids and COD concentration varied greatly over the monitoring period. However, UV transmittance remained zero over the season. The seasonal changes in wastewater quality parameters over the monitoring period are shown in **Figure 4-1**.

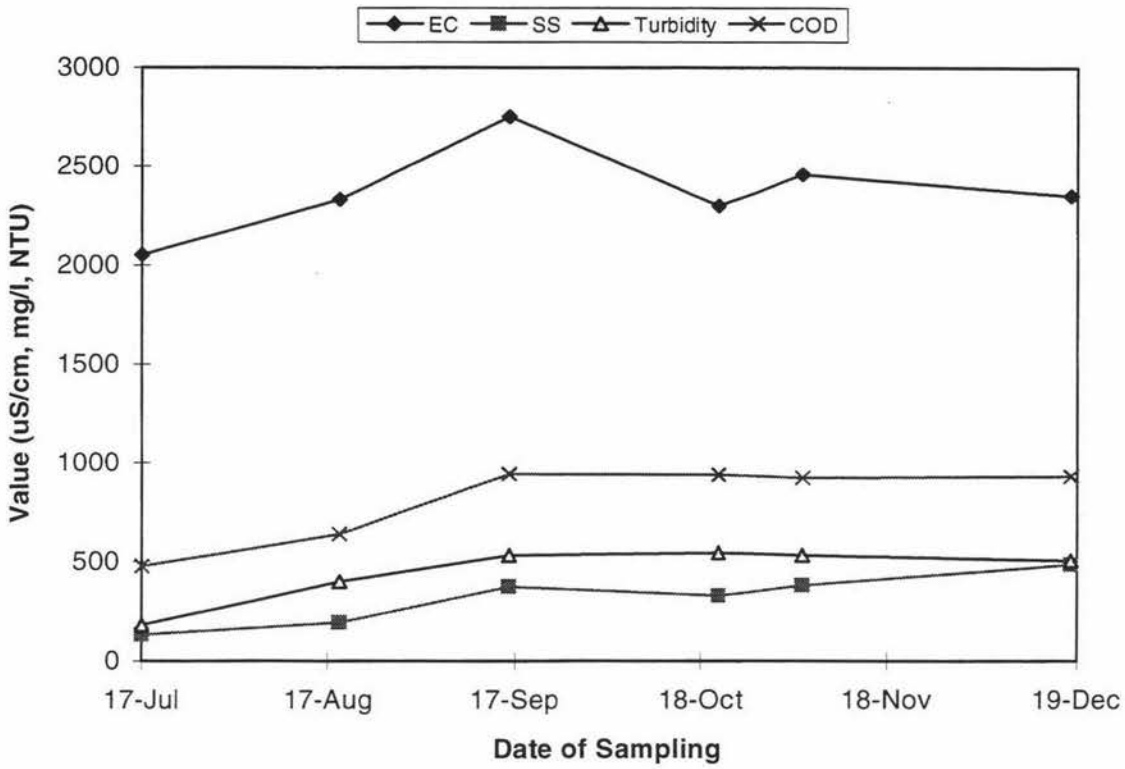

Figure 4-1 Changes in pond effluent quality over the monitoring period

Figure 4-1 shows that over the monitoring period (17 July to 18 December, 1997) wastewater quality parameters changed significantly with season. Wastewater temperature was driven down to 7.1°C in July and reached 18.3°C in December. The suspended solids concentration increased from 131 mg/l in July to 489 mg/l in December, while the COD concentration rose from 478 mg/l in July to over 900 mg/l in September and remained at that level thereafter. Similar to the changes in COD concentration, turbidity level increased sharply to over 500 NTU in September and remained at that level. Though there were changes in wastewater electrical conductivity over the season, there was no definite trend to these changes.

The changes in wastewater BOD are shown in **Figure 4-2**. Wastewater property parameters such as the 5-day BOD (BOD_5), Ultimate BOD (BODu) and the BOD constant (k) remained relatively stable over the season (**Table 4-2**).

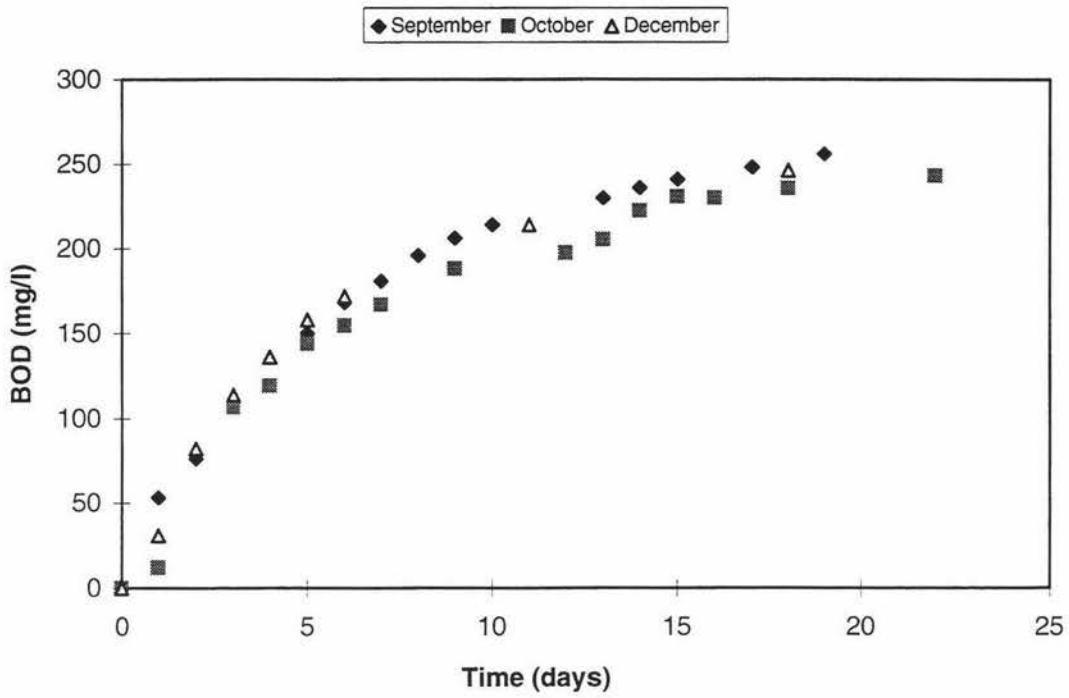

Figure 4-2 BOD of pond treated wastewaters from Massey No.4 Dairy Farm

Table 4-2 Biochemical oxygen demand (BOD) properties of pond treated wastewater from Massey No.4 Dairy Farm (calculated by the Fujimoto Method, Metcalf & Eddy, 1991)

Sampling Date	BOD_5 (mg/l)	BOD_u (mg/l)	k $(day)^{-1}$
16/09/97	153	256	0.182
21/10/97	139	246	0.166
18/12/97	158	258	0.189

Through examining the three measured BOD data sets for the pond effluent from Massey No. 4 Farm Dairy (**Figure 4-2**) it was suspected that there existed a close relationship between these three BOD data sets. Correlation of these three data sets showed that there was strong correlation coefficient (R) among them (**Table 4-3**).

Table 4-3 Correlation coefficient (R) of the BOD data sets for Massey No.4 Farm Dairy pond effluent.

BOD Test Date	September 16	October 21	December 18
September 16	1		
October 21	0.981928	1	
December 18	0.977353	0.968164	1

Due to the similarities among the BOD constants, it may be possible to predict the BOD values for the three tests using one common set of BOD constants. The three sets of BOD data were combined to develop this common set of constants. As shown in **Figure 4-3**, this common set of BOD constants (BOD_5 = 150 mg/l, BOD_u = 253 mg/l and k = 0.179 day^{-1}) fitted the experimental data well. The regression coefficient (R^2) was 0.9845.

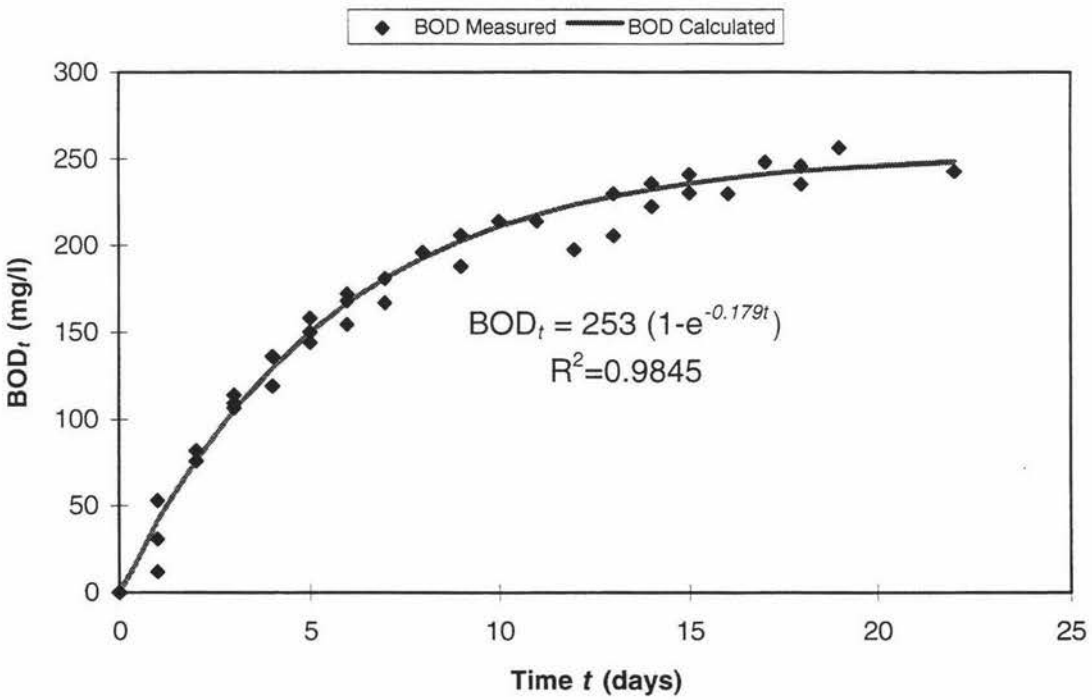

Figure 4-3 Measured and predicted BOD of pond effluent from Massey No. 4 Farm Dairy (combined data sets)

4.1.2 Wastewater from Other Farm Dairies

Wastewater samples from six other farm dairies as described in Chapter Three were collected on 21 October. Their characteristics are summarised in **Table 4-4**.

Table 4-4 Quality parameters of pond effluents from Massey No. 4 and six other farm dairies

Farm Dairy	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F	Massey No. 4
Temperature (°C)	13.0	12.9	14.0	13.2	11.5	13.2	13.5
EC (μs/cm)	2380	386	985	2260	1630	1853	2300
pH	7.78	7.30	7.70	7.64	7.71	7.83	7.71
Turbidity (NTU)	430	77.4	168	532	375	489	546
SS (mg/l)	308	58	168	358	130	304	328
COD (mg/l)	886	190	415	943	832	864	940
BOD_5 (mg/l)	89	9	37	107	81	148	139
Transmittance (%/mm)	16.0	67.7	46.6	15.8	19.7	19.3	21.7
Transmittance (%/cm)	0.0	2.0	0.0	0.0	0.0	0.0	0.0
Absorbance (abs/mm)	0.796	0.170	0.332	0.801	0.706	0.714	0.664

Table 4-4 shows great variations among wastewater quality parameters and among the seven sites. With mean value of 13°C and standard deviation of 0.77°C, temperature showed the least variation among all the parameters. The pH value of the wastewaters showed very little variation among these farm dairies except Farm B. As described in Chapter 3, wastewater from Farm B was mixed with and diluted by rain water, thus having a lower pH value. BOD_5 and Turbidity were the parameters which have the greatest variability. **Figure 4-4** presented both the measured and predicted BOD values for these wastewater samples.

Among the seven sites, wastewater from Farm Dairy B had the best overall wastewater quality. Its concentrations of SS, COD, BOD_5 and turbidity were lowest while its UV transmittance was the highest. It should be noted that no site sampled produced

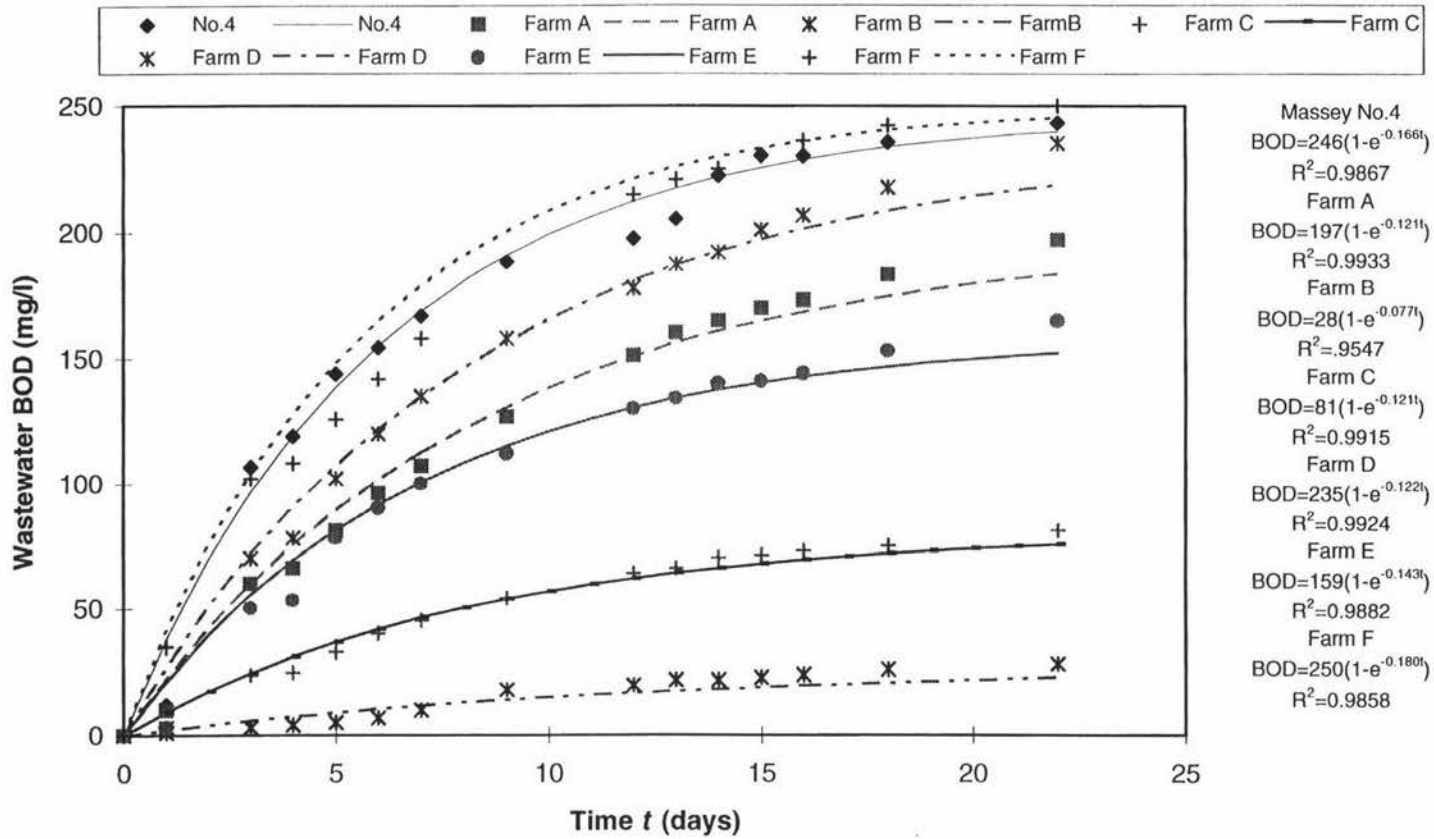

Figure 4-4 Pond treated farm dairy wastewater BOD

wastewater with sufficient UV transmission for effective UV disinfection. All these wastewaters must be further treated to reach the required UV transmittance of 60% through 1 cm quartz cell.

4.2 FARM DAIRY WASTEWATER TREATMENT

4.2.1 Dilution

As shown in **Figure 4-5,** dilution has direct effect on wastewater optical quality. UV transmission increased exponentially as the dilution went further. However, it can be seen that to reach the required UV transmittance of 60%/cm for effective UV disinfection, the dilutions needed were 0.04, 0.08, 0.14, and 0.14, for the raw pond effluent, and the 1.2, 0.45, and 0.22 micron filtrates respectively.

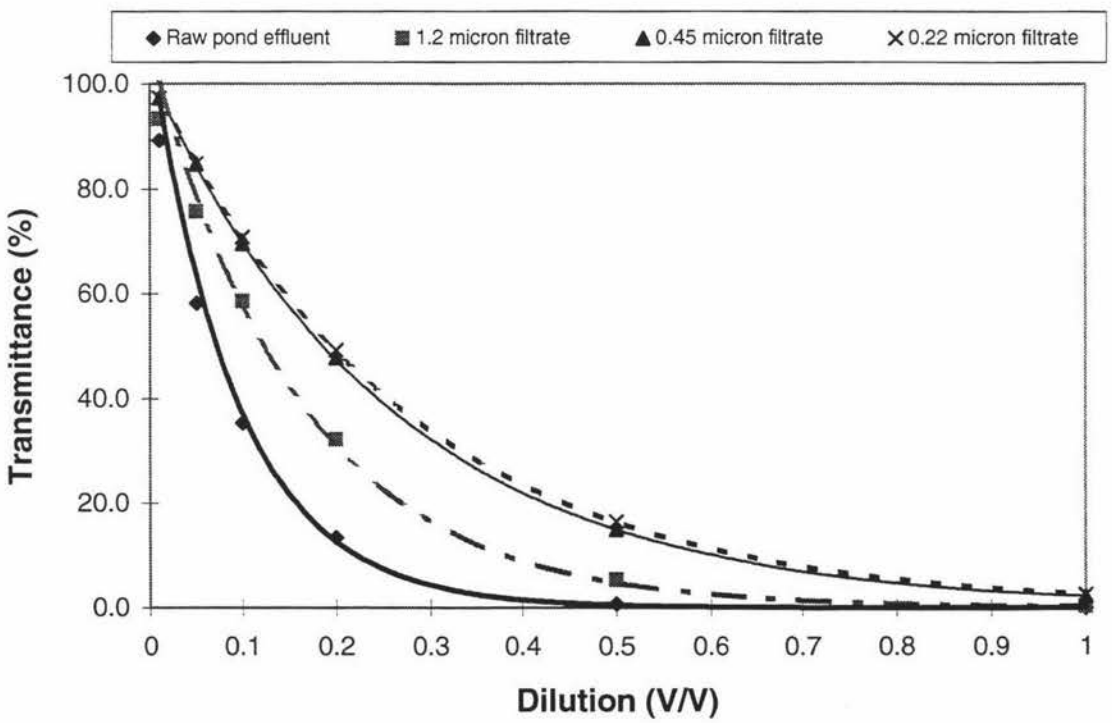

Figure 4-5 Wastewater UV transmittance effected by dilution

Through regression analysis of the UV absorbance (@ 254 nm) data, it was found that a linear relationship exists between wastewater UV absorbance and the dilution of the wastewater (**Figure 4-6**). It was also noticed that by further filtering the 0.45 micron filtrate through 0.22 micron filter UV absorbance was not greatly reduced.

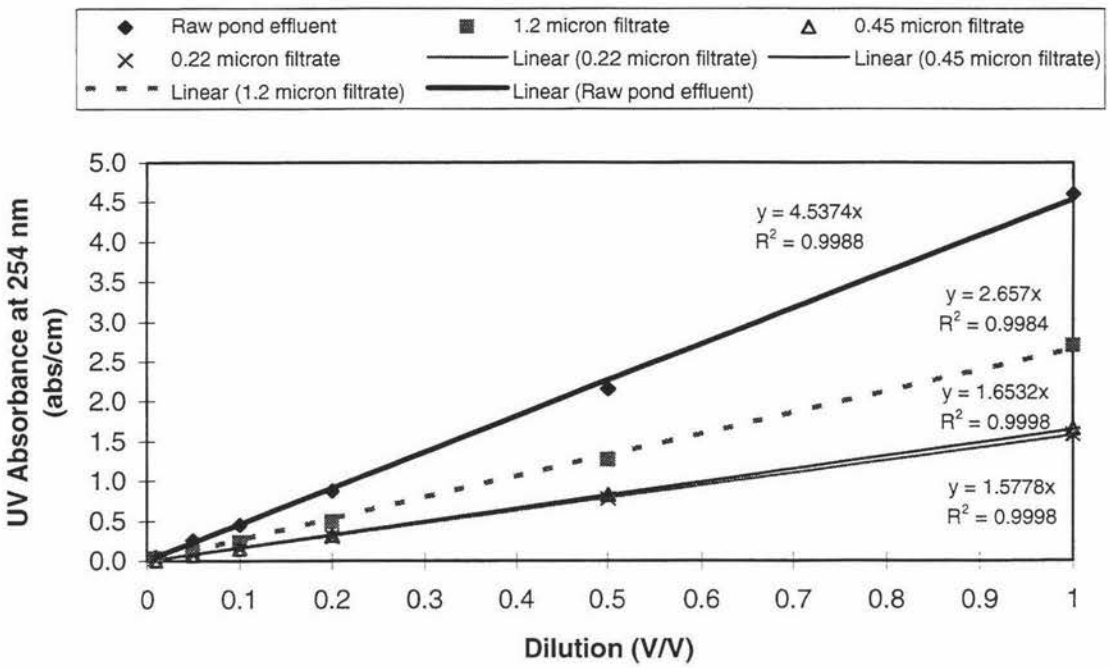

Figure 4-6 UV absorbance as a function of dilution

Tables 4-5 (a), (b) and (c) present the correlation coefficients between dilutions for wastewater UV absorbance, COD, and turbidity. It can be seen that there exist strong relationships among wastewater quality parameters in nearly all the dilution treatments except that of COD at very diluted treatments (dilution 0.05 and 0.01).

Table 4-5 Correlation coefficient (R) between dilutions

(a) UV absorbance

Dilution	1	0.5	0.2	0.1	0.05	0.01
1	1					
0.5	0.992042	1				
0.2	0.994541	0.994642	1			
0.1	0.993948	0.994160	0.999633	1		
0.05	0.988307	0.975982	0.991650	0.992711	1	
0.01	0.991714	0.988455	0.991923	0.992294	0.986645	1

(b) COD

Dilutions	1	0.5	0.2	0.1	0.05	0.01
1	1					
0.5	0.990556	1				
0.2	0.971648	0.968410	1			
0.1	0.974889	0.973396	0.990290	1		
0.05	0.874886	0.896706	0.866139	0.890174	1	
0.01	0.340178	0.342539	0.355035	0.353364	0.490243	1

(c) Turbidity

Dilutions	1	0.5	0.2	0.1	0.05	0.01
1	1					
0.5	0.995987	1				
0.2	0.994648	0.999217	1			
0.1	0.994250	0.999001	0.999964	1		
0.05	0.996570	0.998577	0.999350	0.999198	1	
0.01	0.997376	0.997179	0.998060	0.997803	0.999528	1

Through regression analysis of the wastewater COD, turbidity and UV absorbance data (from both raw pond effluent and filtrates) linear relationships were determined for all the parameters and all the dilutions (**Figure 4-7, 4-8, and 4-9**). Dilution treatment reduced wastewater UV absorbance (**Figure 4-7**) and turbidity (**Figure 4-9**) proportionally. However, wastewater COD concentration was reduced proportionally only at higher concentrations (dilution 0.5 through 0.1). At high dilution ratios (dilution 0.05 and 0.01) this linear relationship deteriorated, for the regression coefficient R^2 went down to less than 0.7295. It was also noticed that the error caused by estimating the COD value using these regression formulae will increase at high dilution ratios. A

review of the experimental data showed that COD values of these samples were very low (3 to 48 mg/l and over two-thirds of them were less than 20 mg/l). This reduced regression coefficient (R^2) may be related to the inaccuracy of the COD measurement method especially at low COD concentrations.

It must be noted that though the regression coefficients (R^2) were higher than 0.98 for the turbidity data, the resulting linear relationship was not the expected (**Figure 4-9**). For example, by diluting raw sample to dilution 0.5, one expects the turbidity is reduced to half the original value. It was also noticed that all the linear regression formula tended to under estimate wastewater turbidity value. For example, the regression formula may under estimate turbidity level by 20% for dilution 0.5, and by 35% for dilution 0.05.

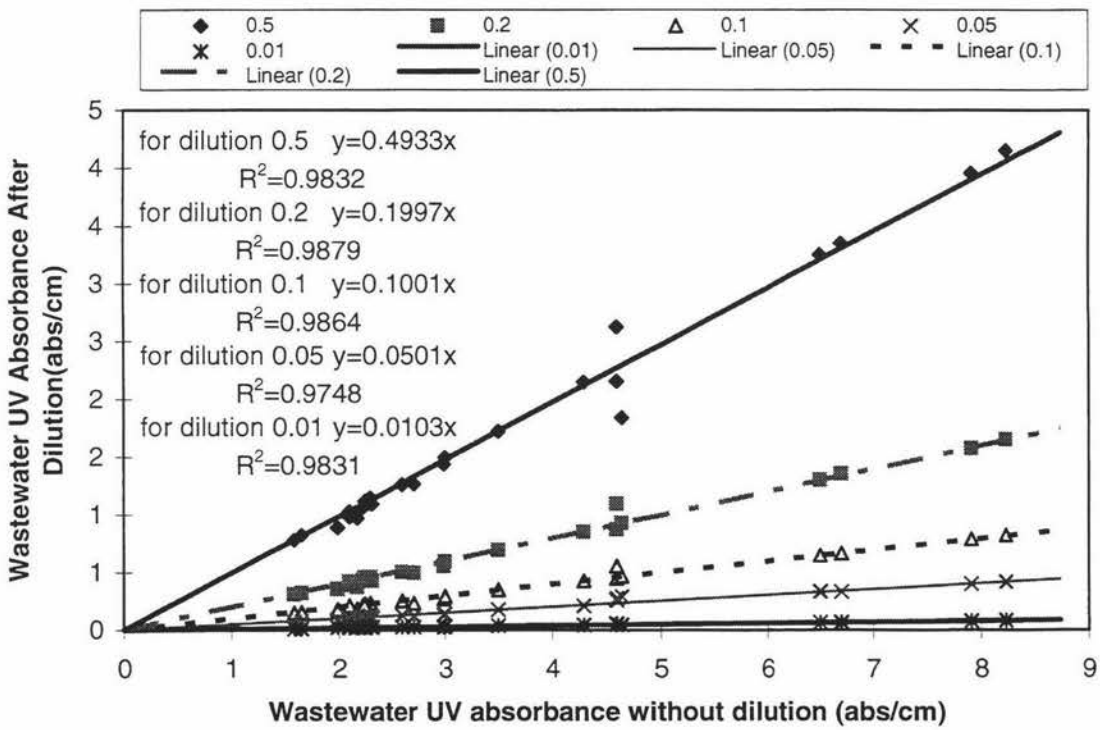

Figure 4-7 Effect of dilution on wastewater UV absorbance

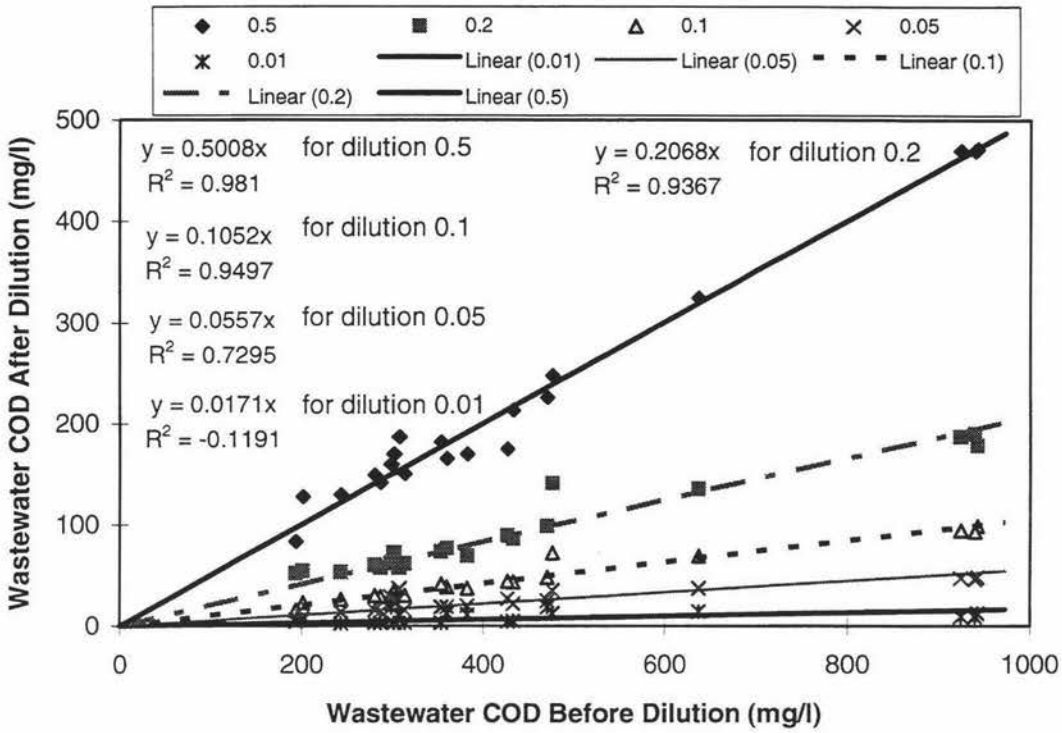

Figure 4-8 Effect of dilution on Wastewater COD

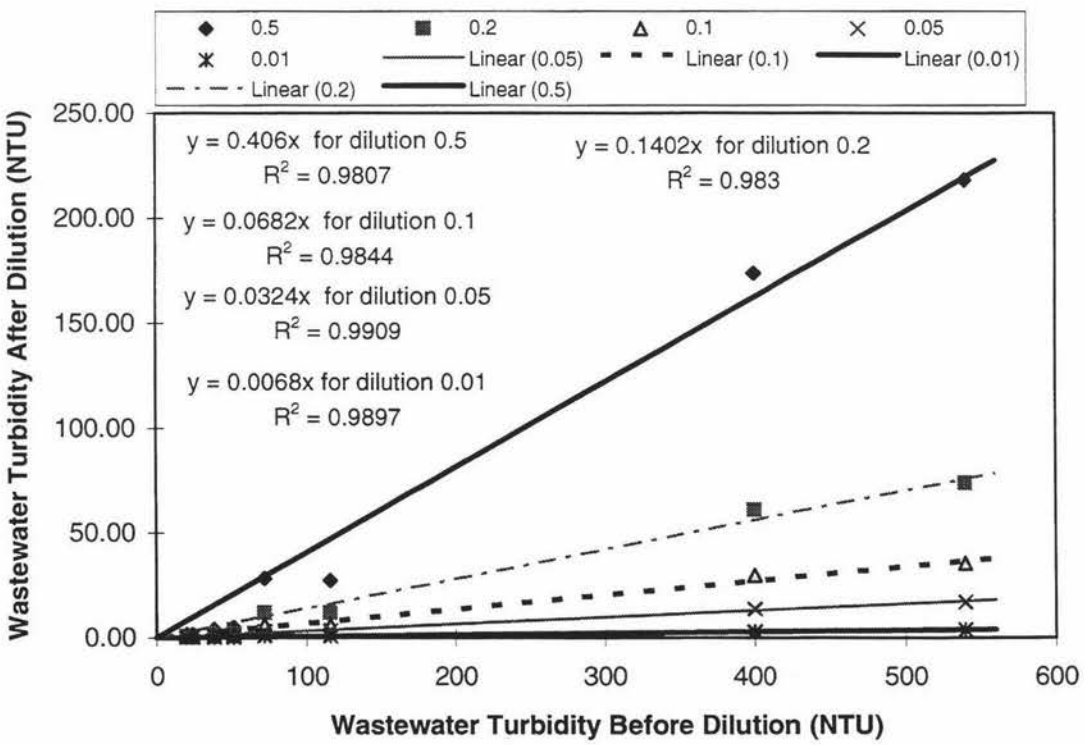

Figure 4-9 Effect of dilution on wastewater turbidity

The experimental results presented above show that dilution reduced wastewater concentration proportionally. However, the nature of the wastewater was not altered by the dilution treatment, for the relationship between wastewater characteristics was not affected.

4.2.2 Filtration

As shown in **Table 4-6**, the characteristics of farm dairy wastewater changed after filtration treatment. Filtration through a 1.2 micron filter removed about half the COD and 80% of the turbidity of the raw pond effluent. Further filtration through 0.45 micron filter removed another 14% of the COD and 11% of the turbidity of the raw samples. However, continued filtration through 0.22 micron filter removed only 2.6% of the COD and 5.6% of the turbidity of the raw pond effluent. Wastewater UV transmittance (@ 254 nm) was increased from zero to 0.05, 0.8, and 1.1%/cm following this sequential filtration.

Table 4-6 Characteristics of raw and filtered wastewater from Massey No. 4 Dairy Farm pond

Treatment	COD (mg/l)	SS (mg/l)	Turbidity (NTU)	EC (μS/cm)	UV Transmittance (%/cm @ 254 nm)
Raw pond effluent	809	317	450	2374	0.0
	(201)	(131)	(142)	(229)	(0.0)
1.2 micron filtrate	413	0	94	n.m.	0.05
	(64)	(0)	(31)		(0.08)
0.45 micron filtrate	296	0	45	n.m.	0.8
	(53)	(0)	(9.3)		(0.7)
0.22 micron filtrate	275	0	20	n.m.	1.1
	(54)	(0)	(6.4)		(0.8)

where: EC = Electrical Conductivity, SS = Suspended Solids, COD = Chemical Oxygen Demand, and BOD_5 = 5 day Biochemical Oxygen Demand; n.m. = not measured; all value reported as: mean (standard deviation) resulting from six tests.

As shown in **Figure 4-10**, wastewater quality was improved after filtration treatment. It can be seen from **Figure 4-10** (a) and (b) that pond treated wastewater UV transmittance remained zero throughout the season and its UV absorbance stayed above 4.6. After filtration through a 1.2 micron filter, wastewater UV transmittance slightly improved while its UV absorbance slightly reduced for the first two tests. UV

transmittance through 1.2 micron filtrate remained zero for the remaining four tests due to the significant ($P<0.05$) increase in pond treated wastewater UV absorbance. Further filtration through 0.45 and 0.22 micron filter significantly ($P<0.05$) improved UV transmission in all tests. It can also be seen that UV transmission through the pond treated wastewater and the filtrates was deteriorating in the testing season.

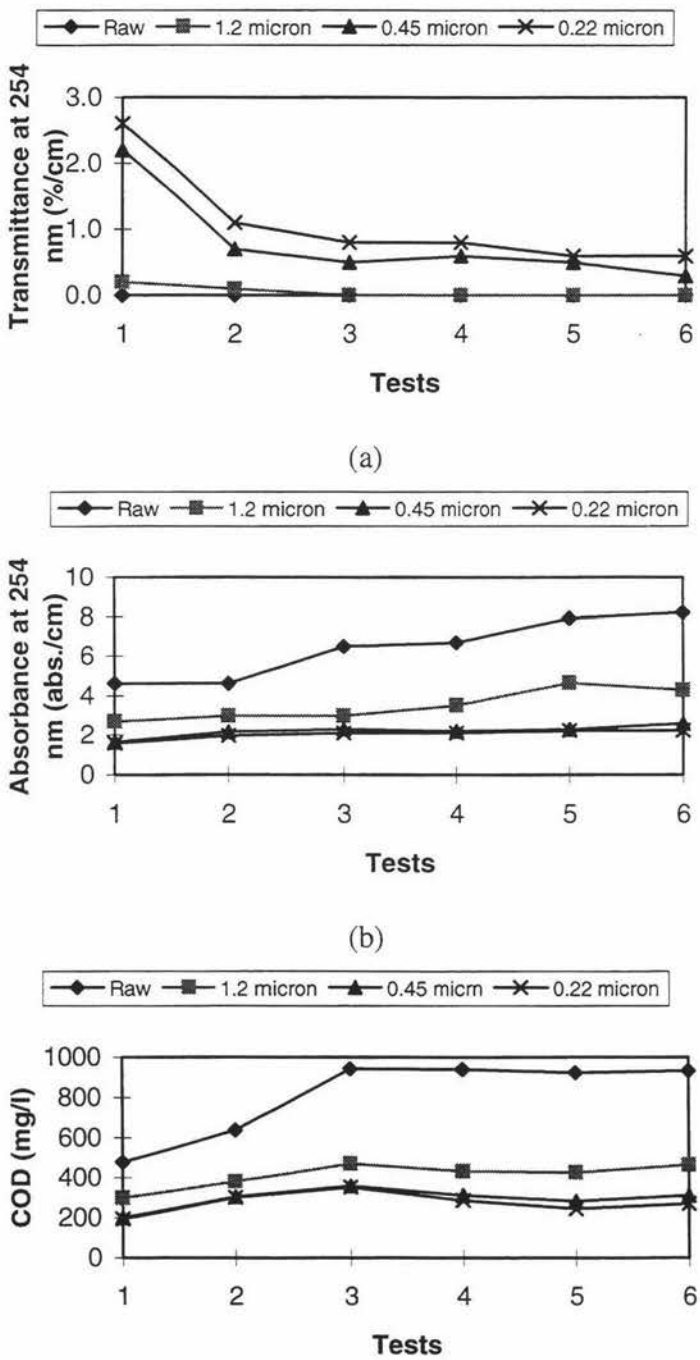

Figure 4-10 Effect of filtration on wastewater quality

Pond treated wastewater COD values increased from 478 mg/l in July to 943 mg/l in September and remained higher than 924 mg/l in the following tests. The COD values of the filtrates followed a similar trend to that of the pond treated wastewaters (**Figure 4-10 (c)**). It can also be seen that the reduction in COD values was significant ($P<0.05$) by filtering pond treated wastewater through 1.2 micron and by further filtering the 1.2 micron filtrate through 0.45 and 0.22 micron membranes. However, the COD levels were not significantly ($P>0.05$) different between the 0.45 micron and 0.22 micron filtrates.

Filtration treatment altered the particulate distribution in the wastewater. This resulted in changes of relationship among wastewater COD, turbidity, and UV absorbance.

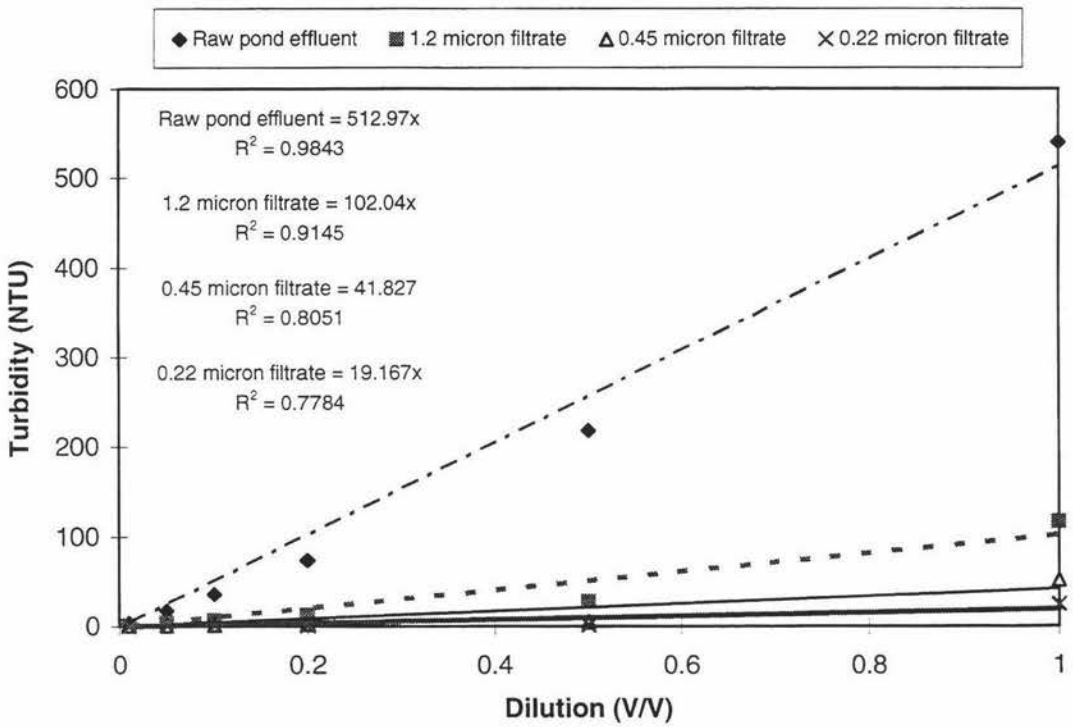

Figure 4-11 Wastewater turbidity as function of filtration and dilution

From **Figure 4-11** , raw pond effluent had the highest turbidity value while the 0.22 micron filtrate had the lowest turbidity level. It was also noticed that further filtration through 0.45 and 0.22 μm greatly reduced turbidity which resulted poor regression coefficient (R^2 = 0.8051 and 0.7784 respectively) due to the inaccuracy of the turbidity meter at low turbidity levels (i.e., less than 1 NTU).

On the contrary, the regression coefficient (R^2) for wastewater COD was not affected significantly ($P>0.05$) (**Figure 4-12**) by filtration treatment. Filtration through 1.2 micron filter removed half the COD concentration of the pond treated wastewater. Further filtration through 0.45 micron filter removed another 12% of the COD level of the raw pond effluent. However, continued filtration through 0.22 micron filter had negligible effect in reducing COD concentration.

Figure 4-13 showed also the linear regression coefficient (R^2) was higher between UV absorbance and COD than that between UV absorbance and turbidity.

From the experimental results presented above, it can be seen that filtration altered the nature of the wastewater by removing the particulates. The relationship between wastewater characteristics changed as a result of the filtration treatment.

4.2.3 Coagulation Followed by Filtration

At 0.007 N/L cation (Zn^{2+}or Al^{3+}) concentration, aluminium sulphate ($Al_2(SO_4)_3 \cdot 18H_2O$, called alum in the following context) solution was found more effective than zinc sulphate ($ZnSO_4 \cdot 7H_2O$) in coagulating the colloidal materials in the farm dairy wastewater (**Table 4-7**).

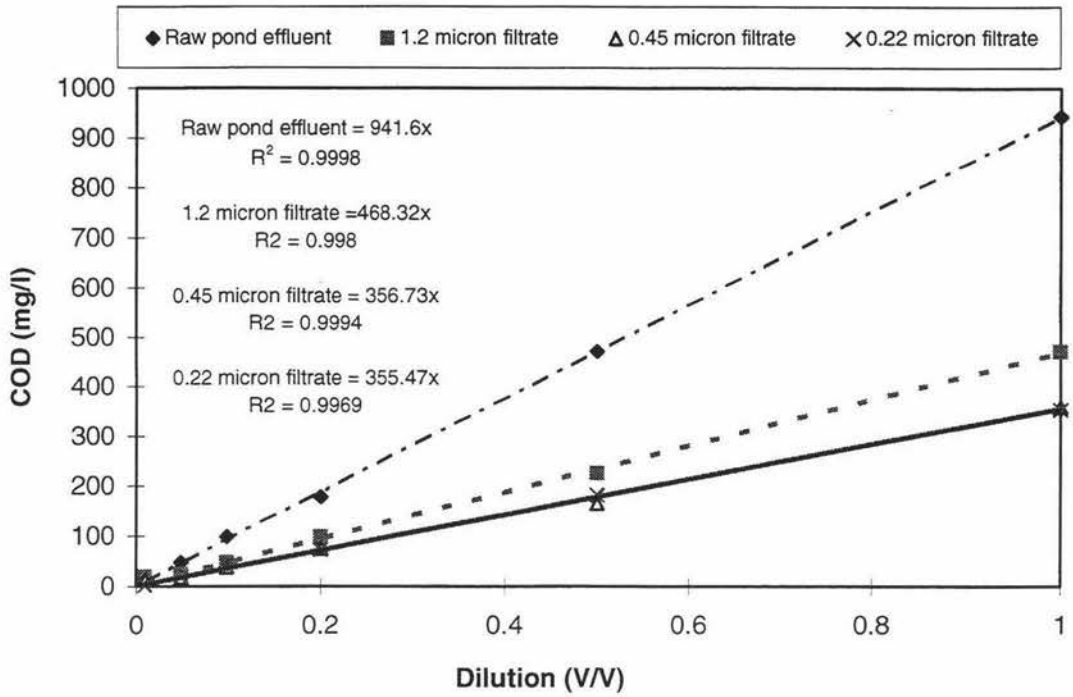

Figure 4-12 Wastewater COD as function of filtration and dilution

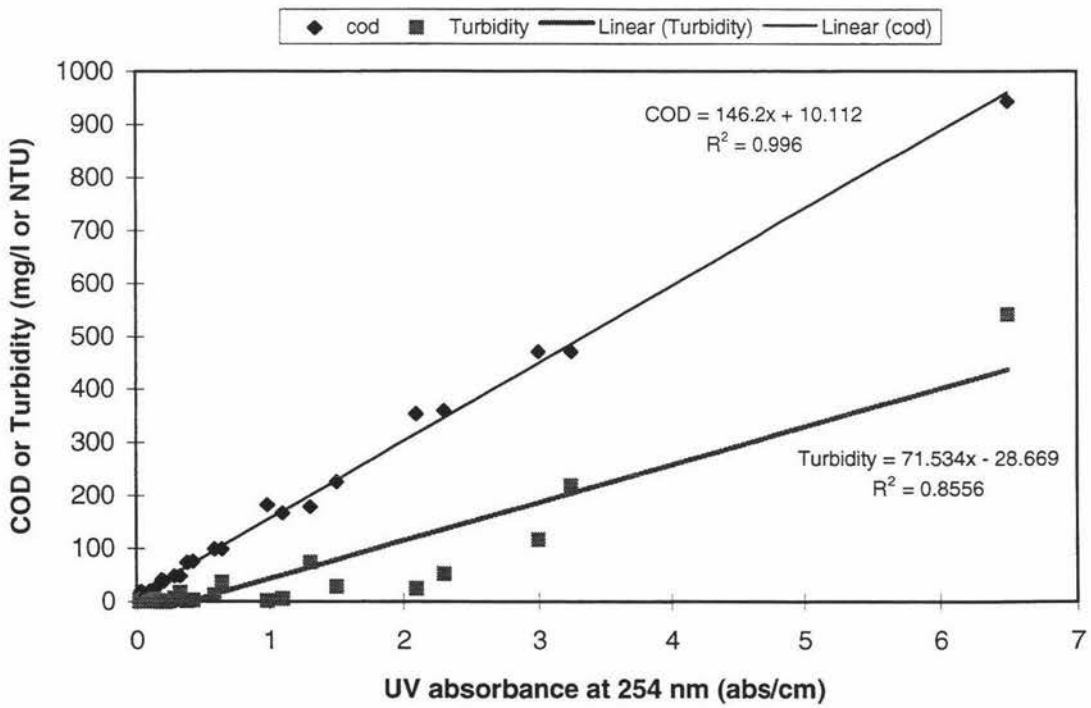

Figure 4-13 Wastewater COD and turbidity as function of UV absorbance with dilution and filtration treatment

Table 4-7 Coagulation effectiveness by (773 mg/l) alum ($Al_2(SO_4)_3 \cdot 18H_2O$) and (1000 mg/l) zinc sulphate ($ZnSO_4 \cdot 7H_2O$) solution

Coagulant	COD (mg/l)	UV Transmittance (%/cm @ 254 nm)	UV absorbance (abs/cm @ 254 nm)
Alum	61.7	28.5	0.019
Zinc sulphate	175.3	11.4	0.054

Based on the findings in **Table 4-7**, subsequent coagulation treatment in this study was by alum.

As shown in **Figure 4-14,** initially, with the increase of dose, wastewater UV transmittance increased proportionally. After the dose of 1600 mg/l this trend slowed down but the UV transmittance continued to increase till 29%/cm at a dose of around 2400 mg/l. UV transmittance went down beyond this critical point.

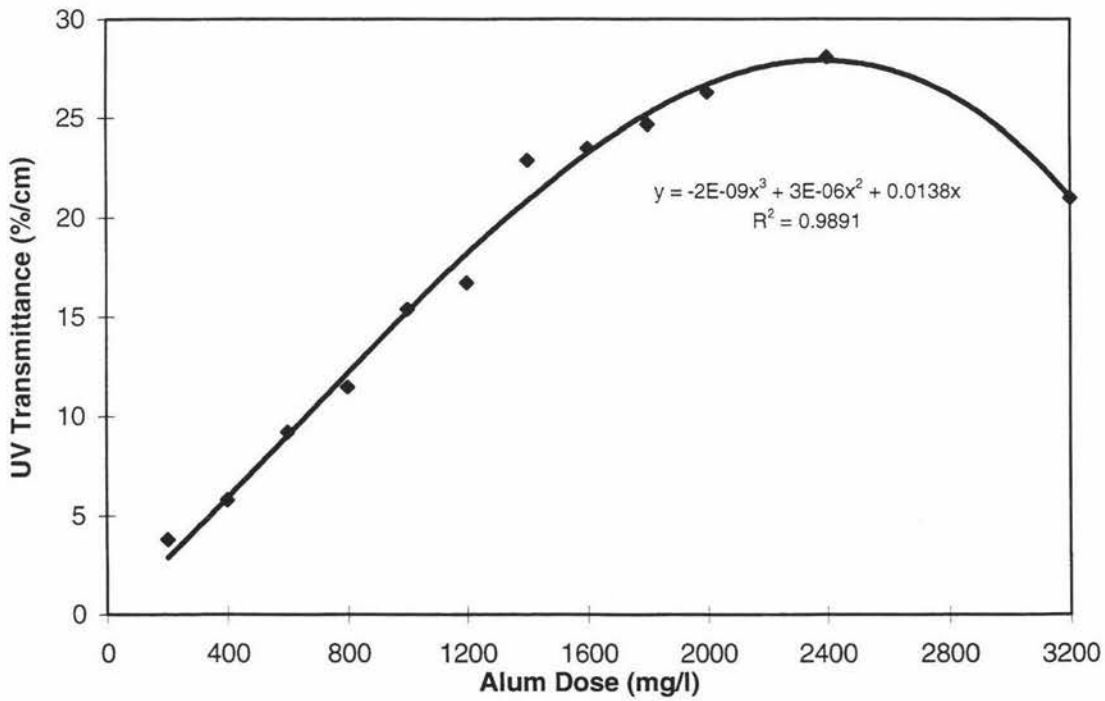

Figure 4-14 UV transmittance of pond treated wastewater after alum coagulation followed by 0.45 micron filtration

The effect of stirring duration and settling time on wastewater UV transmission was studied by using stirring duration and settling time combinations in the 1600 mg/l coagulation treatment of farm dairy wastewater (**Figure 4-15**). As expected, continued stirring for 24 hours (1440 min.) gave the poorest UV transmission. Statistical analysis showed that there were no significant ($P>0.05$) differences among the UV transmittance resulting from stirring times of 1, 2 and 5 minutes. UV transmittance was significantly different ($P<0.05$) between 30 minutes stirring time and 1440 minutes stirring time as well as between 30 minutes stirring time and 5 minutes stirring time.

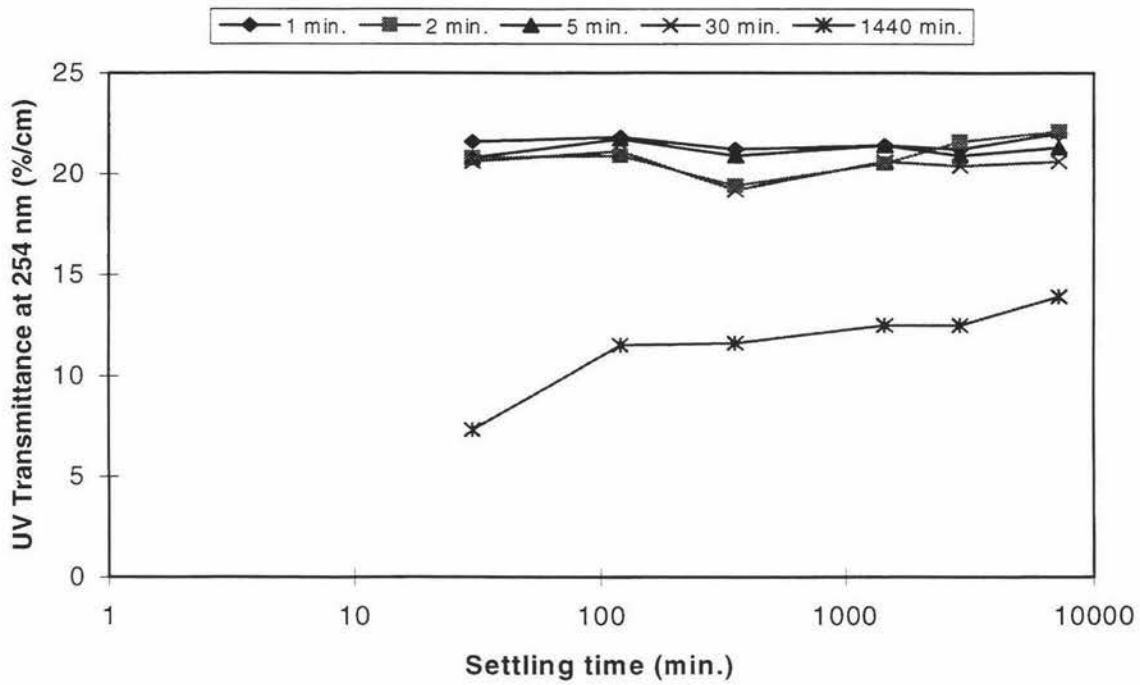

Figure 4-15 Effect of stirring and settling time on UV transmission

The effect of settling time on UV transmission, using wastewater from six other farm dairies was studied at a dose of 1600 mg/l. Results are shown in **Figure 4-16.** UV transmittance through all the wastewaters increased with settling time. The average increase in UV transmittance was 6.3%/cm or 21 per cent.

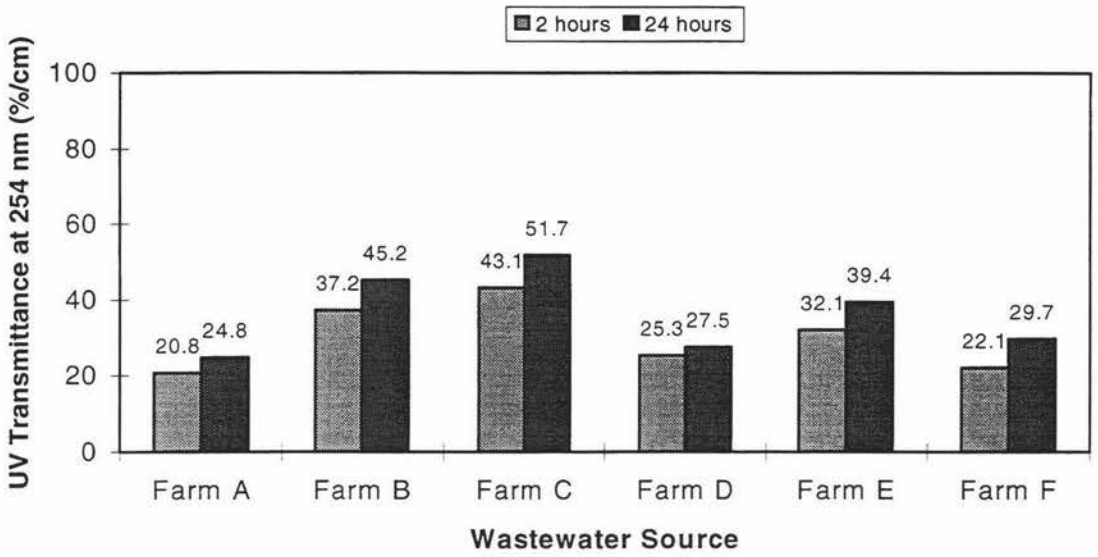

Figure 4-16 Effect of settling time on UV transmission through wastewaters

After coagulation treatment at 200 - 1600 mg/l doses followed by 0.45 micron filtration, wastewater quality parameters such as turbidity, UV absorbance and COD were improved. Through statistical analysis, it was found there existed strong correlation (R>0.97) among these three parameters (**Table 4-8**).

Table 4-8 Correlation coefficient (R) among alum dose, turbidity, UV absorbance and COD

Parameter	dose	Turbidity	UV absorbance	COD
dose	1			
Turbidity	-0.97855	1		
UV absorbance	-0.97716	0.995072	1	
COD	-0.97292	0.978608	0.989421	1

With the increase of alum dose all the three parameters (turbidity, absorbance and COD) reduced their values (R<0). After regression analysis, it was found that linear relationship existed among the turbidity, UV absorbance and COD concentration of the treated wastewaters (**Figure 4-17**, and **Figure 4-18**).

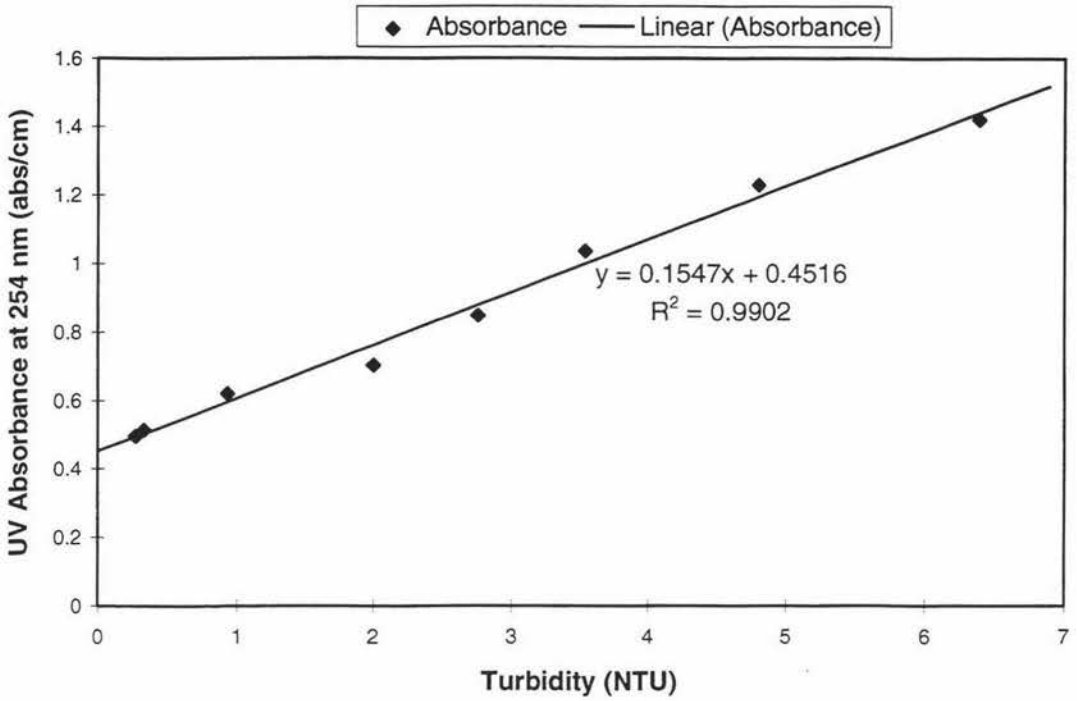

Figure 4-17 Relationship between turbidity and UV absorbance after 200 - 1600 mg/l alum coagulation treatment

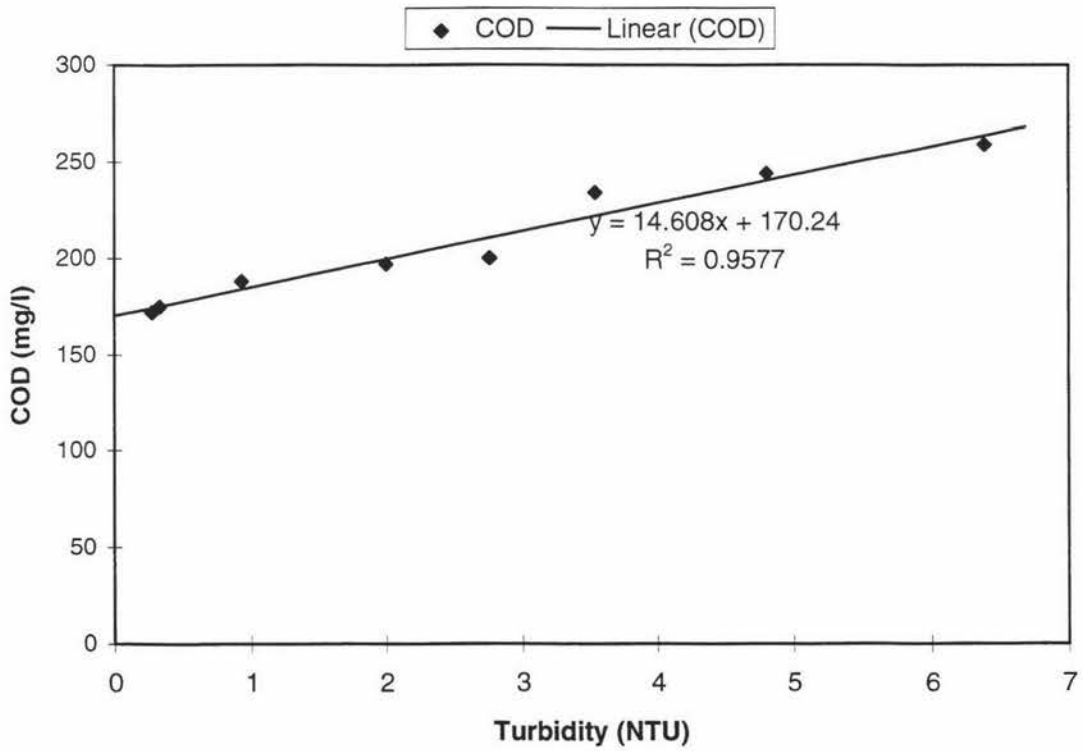

Figure 4-18 Relationship between turbidity and COD after alum coagulation treatment

From **Figure 4-17**, it can be seen that at a high dose (1600 mg/l) followed by filtration treatment, wastewater turbidity reduced to virtually zero. UV absorbance at this point (about 0.45 abs/cm) was resulted mostly from the soluble materials in the wastewater.

From **Figure 4-18**, it can be seen that even turbidity was completely removed, wastewater COD was still about 170 mg/l. This COD value must be associated with the dissolved matter.

From the coagulation treatment results, it was found that a considerable amount of the COD was contributed by the dissolved materials. Coagulation followed by filtration treatment removed only the suspended solids and colloidal material which contribute to turbidity and most of the COD. The best UV (254 nm) transmittance achieved by this treatment was less than 30%/cm. The remaining UV absorbing material was dissolved organic and possibly inorganic matter which must be removed by other treatment techniques.

4.2.4 Centrifugation

Ultracentrifugation was used to investigate the nature of the wastewater after coagulation and 0.45 micron filtration treatment. As shown in **Figure 4-19**, ultracentrifugation at 105,000 g for one hour improved wastewater UV transmittance only slightly, at high alum doses. Statistical analysis of the experimental results showed that there was no significant ($P>0.05$) difference between wastewater UV transmittance before and after ultracentrifugation treatment.

4.2.5 Adsorption

Farm dairy wastewater was coagulated by 1600 mg/l alum, filtered through 0.45 micron filter and then treated by activated carbon (AC) adsorption. As a comparison, pond treated wastewater was also treated by activated carbon alone. As shown in **Figure 4-20**, the effectiveness of activated carbon in improving UV transmission through wastewater is much higher in the alum treated 0.45 micron filtrate. It can also be seen

that both the raw pond effluent and the alum treated 0.45 micron filtrate data points can be fitted with logarithmic curve.

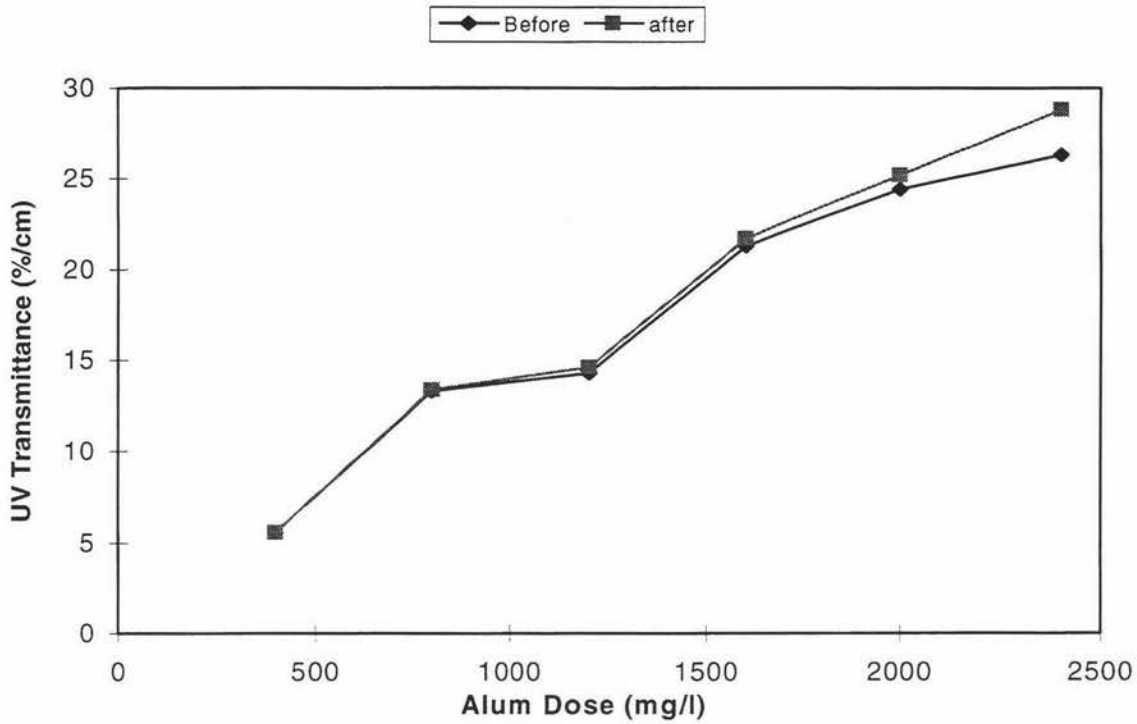

Figure 4-19 UV Transmittance of alum coagulated wastewater before and after ultracentrifugation treatment

Wastewater was also treated by bark adsorption. As shown in **Figure 4-21**, bark treatment of the coagulated and 0.45 micron filtrate reduced UV transmission. Bark A treatment of raw pond effluent increased UV transmittance slightly from 0.3%/cm to 0.7%/cm, while Bark B treatment made no change in pond treated wastewater UV penetration. It can also be seen that treatment by bark B (Fine) resulted lower UV transmission than that by Bark A (Coarse).

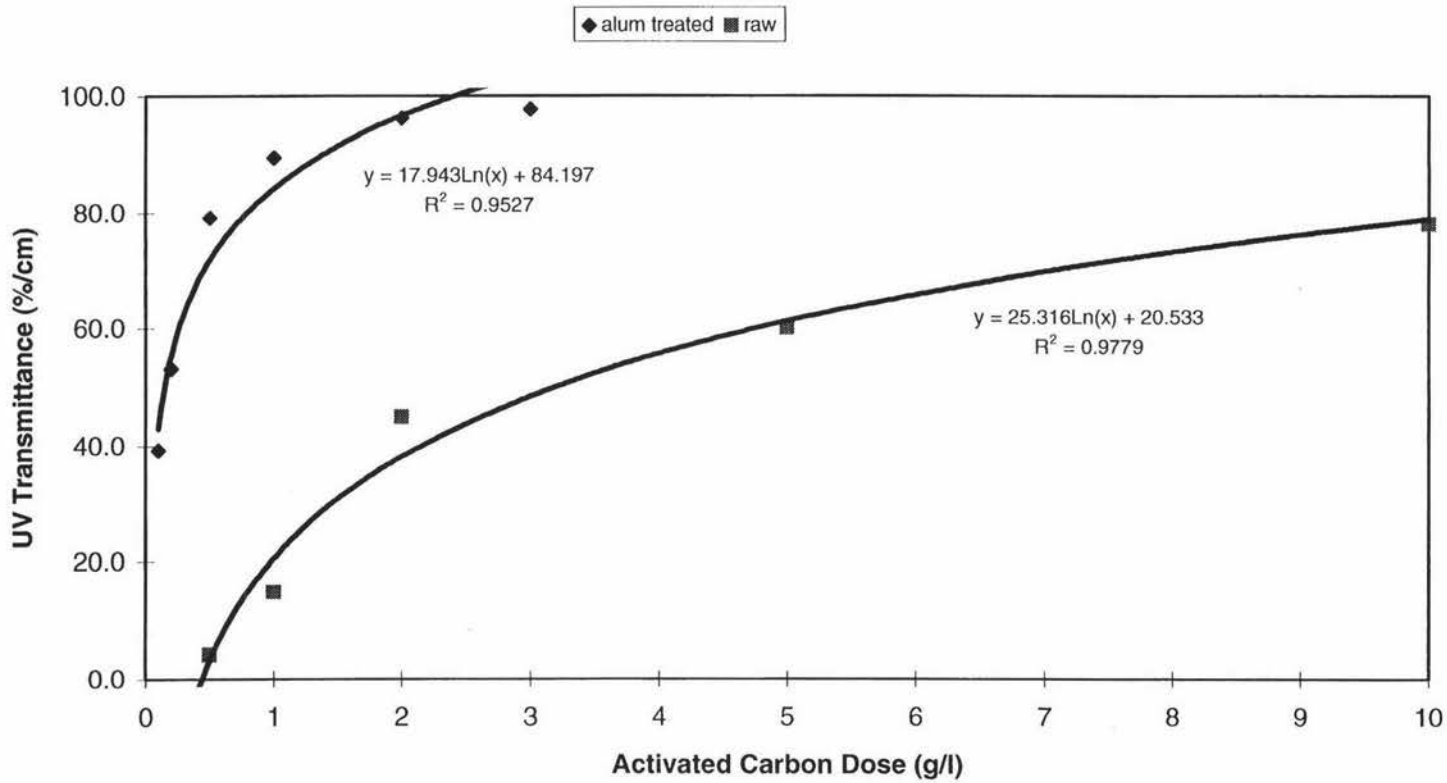

Figure 4-20 UV transmittance of wastewater after activated carbon adsorption treatment

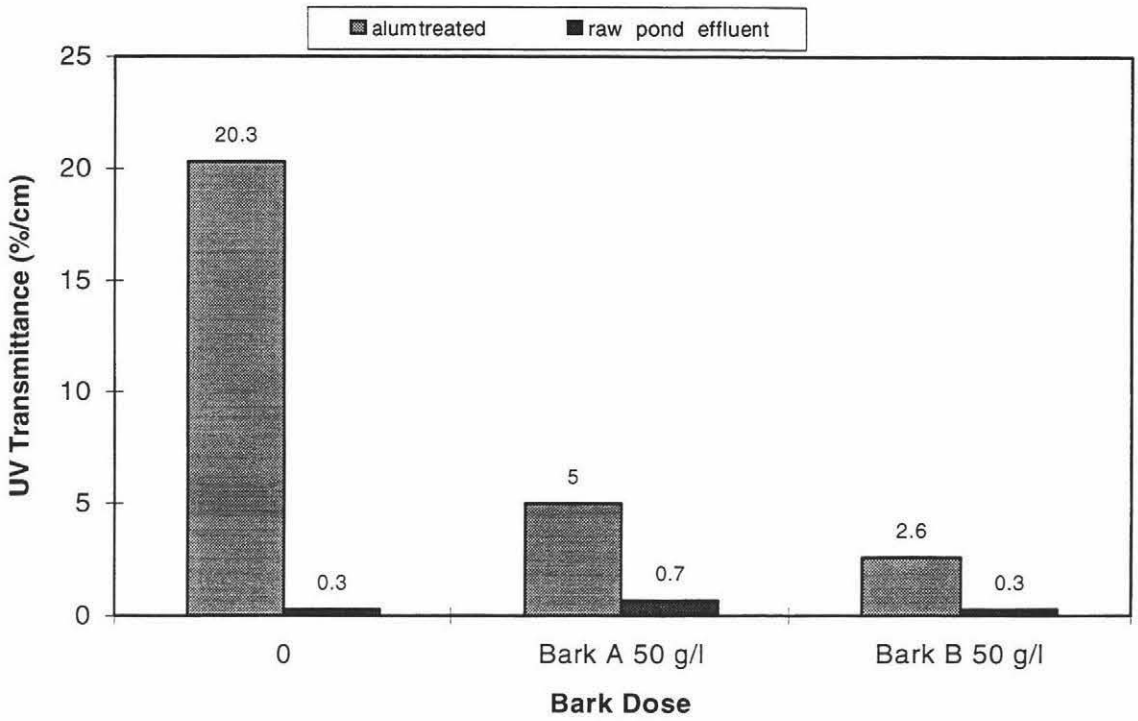

Figure 4-21 UV transmittance of wastewater affected by bark adsorption treatment

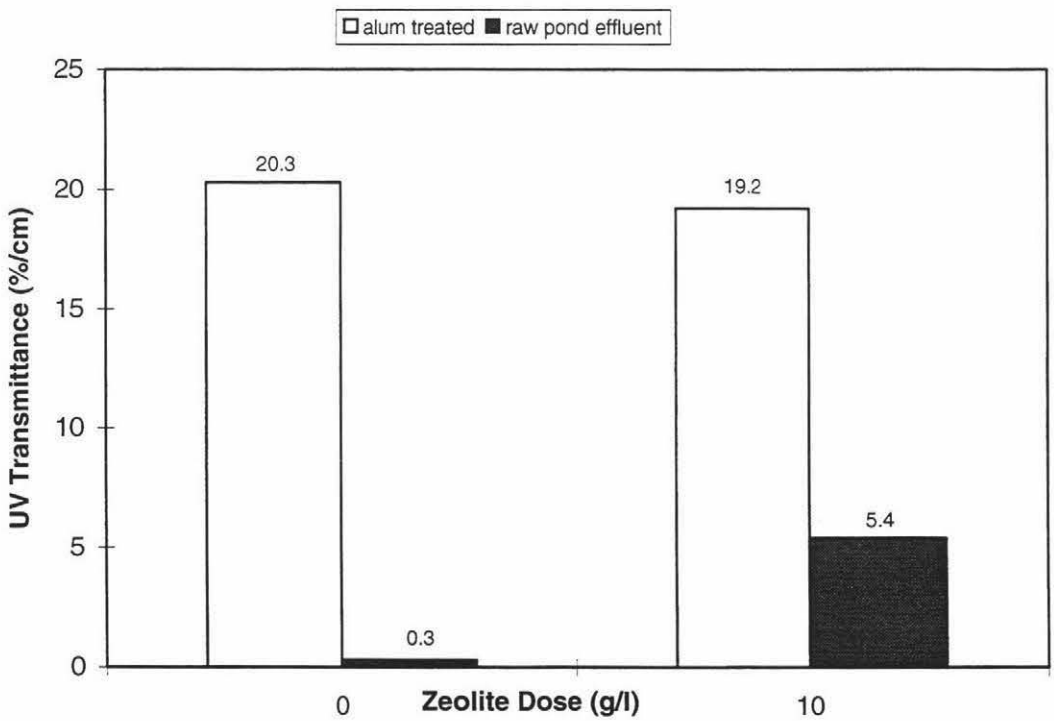

Figure 4-22 UV transmittance of wastewater affected by zeolite adsorption treatment

UV transmission through pond treated wastewater was improved after treatment by zeolite, but UV penetration reduced slightly following zeolite treatment (**Figure 4-22**) of the 1600 mg/l alum coagulated (0.45 micron) filtrate.

The effect of reaction time in activated carbon treatment was also studied with 1600 mg/l coagulated 0.45 micron filtrate and the results are shown in **Figure 4-23**. It was found that at lower activated carbon dose of 0.2 g/l wastewater UV transmittance continued to improve from 47.8%/cm at 24 hours to 61.8%/cm at 120 hours. At an activated carbon dose of 0.5 g/l, wastewater UV transmittance improved from 75.7%/cm at 24 hours to 86.3%/cm at 48 hours and remained at that level thereafter. At a higher activated carbon dose of 5 g/l, wastewater UV transmittance reached its highest value in 24 hours and maintained that level afterwards.

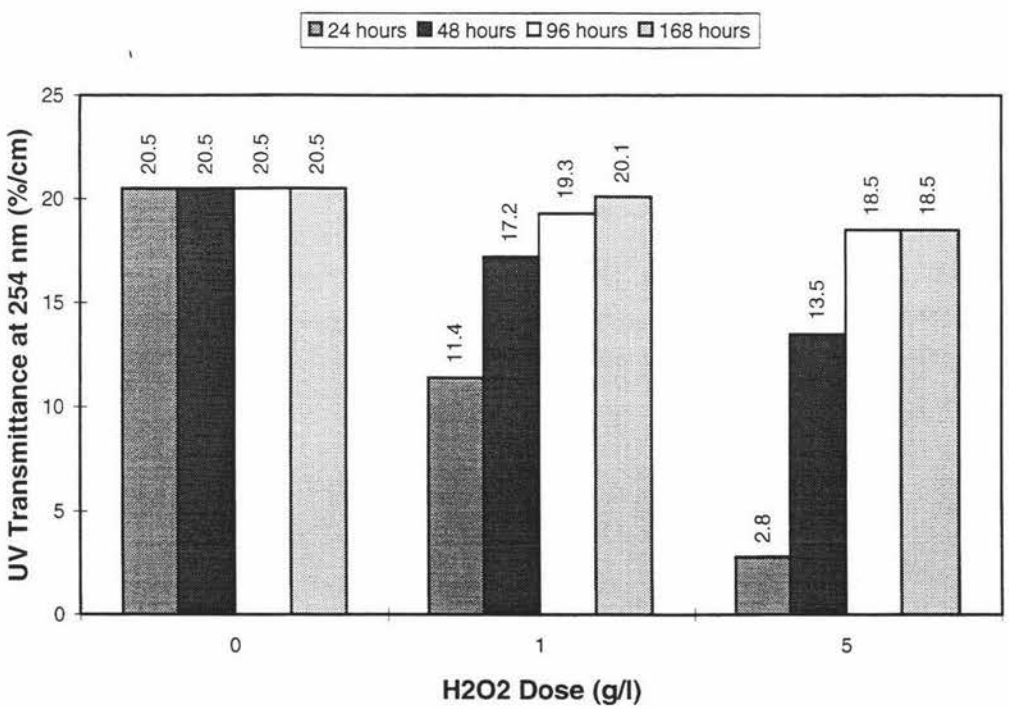

Figure 4-23 Effect of activated carbon dose and reaction time

4.2.6 Oxidation

The effect of hydrogen peroxide dose and reaction duration was studied with 1600 mg/l coagulated 0.45 micron filtrate and the results were shown in **Figure 4-24**. At both hydrogen peroxide doses, wastewater UV transmittance deteriorated immediately after the dosing. Wastewater UV transmittance regained gradually for the 1 g/l dosage treatment in seven days, but failed to attain the original level for the 5 g/l dosage treatment. It was found that higher hydrogen peroxide dose resulted in lower UV transmittance too.

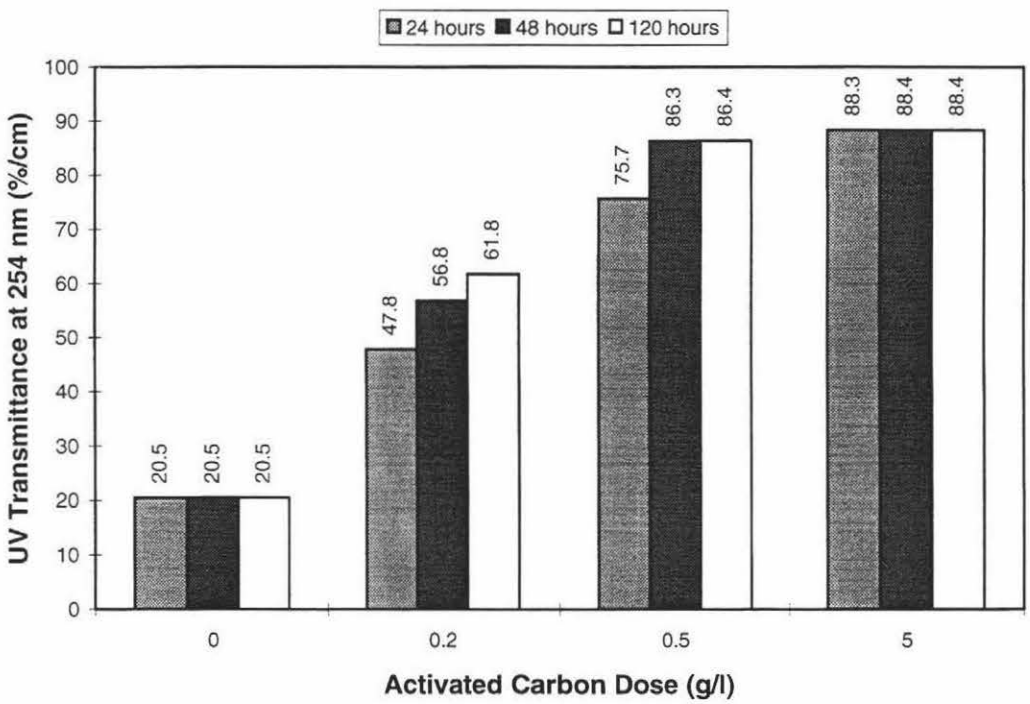

Figure 4-24 Effect of hydrogen peroxide dose and reaction time

To investigate the role of hydrogen peroxide on UV transmittance, a water sample containing 1 g/l hydrogen peroxide was scanned and it was found that the addition of hydrogen peroxide reduced UV Transmittance. At 254 nm wavelength, this hydrogen peroxide solution resulted in 0.619 abs/cm or 24% transmittance in a 1 cm quartz cell. From this finding, it could be assumed that the poorer UV transmittance in the hydrogen

peroxide treatment at higher dose was possibly due to the residual hydrogen peroxide concentration.

4.3 WASTEWATER ABSORBANCE SPECTRA

Absorbance spectra between 200 and 800 nm were obtained on a Shimadzu 160A UV/VIS Spectrophotometer for both raw and treated pond effluent. Through statistical analysis (Anova, single factor) of the spectral data, the following results were obtained.

4.3.1 Absorbance Spectra of Raw and Filtered pond effluent

Through statistical analysis, it was found that the absorbance spectrum of pond treated wastewater was significantly different ($P<0.05$) from that of the 1.2 micron filtrate. The absorbance spectrum of 1.2 micron filtrate was significantly different ($P<0.05$) from that of the 0.45 and 0.22 micron filtrates ($P<0.05$). There was no significant ($P>0.05$) difference between the absorbance spectrum of 0.45 micron filtrate and that of the 0.22 micron filtrates (See **Appendix B-1** for these spectra).

From **Figure 4-25**, it can be seen that filtration through a 1.2 micron filter removed 77.5% to 58.5% of the absorbance in the visible light range. These absorbance reductions fell to 28.7% at 200 nm wavelength. Further filtration through 0.45 and 0.22 micron filter removed more absorbing material. Filtration through a 0.22 micron filter removed 100% to 86.4% of the absorbance in the visible light range and between 86.4% and 57.5% in the UV range.

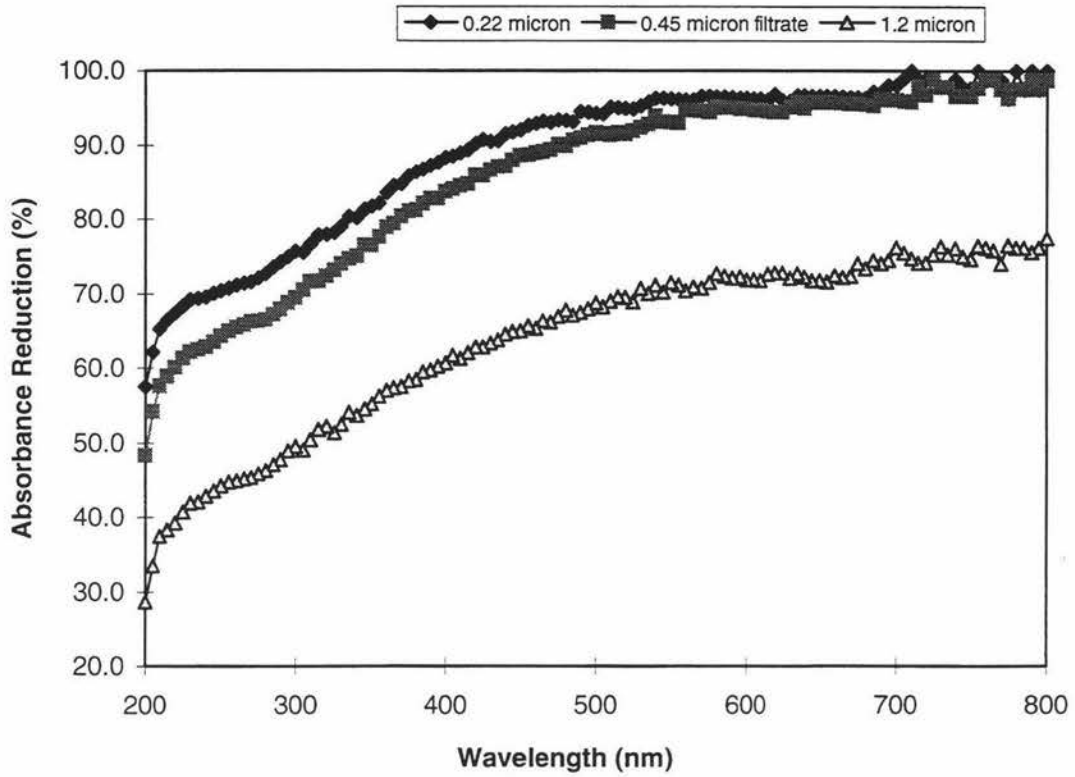

Figure 4-25 Absorbance reduction of pond treated wastewaters after filtration treatment

4.3.2 Absorbance Spectra of Raw and Coagulated-Filtered Pond Effluent

Statistical analysis of the absorbance spectra from pond treated wastewater and coagulated-filtered wastewaters showed that alum coagulation followed by 0.45 micron filtration significantly ($P<0.05$) improved wastewater optical quality. There was no significant ($P>0.05$) difference between the spectrum of 800 mg/l alum coagulated wastewater and that of 1200 mg/l alum coagulated wastewater. Similarly the absorbance spectra were not significantly ($P>0.05$) different between wastewaters coagulated by 1600 mg/l and 1200 mg/l alum, 2000 mg/l and 1600 mg/l alum, and 2400 mg/l and 2000 mg/l alum. A significant difference ($P<0.05$) in absorbance spectra existed between 1600 mg/l and 800 mg/l alum coagulated wastewaters (See **Appendix B-2** for these spectra).

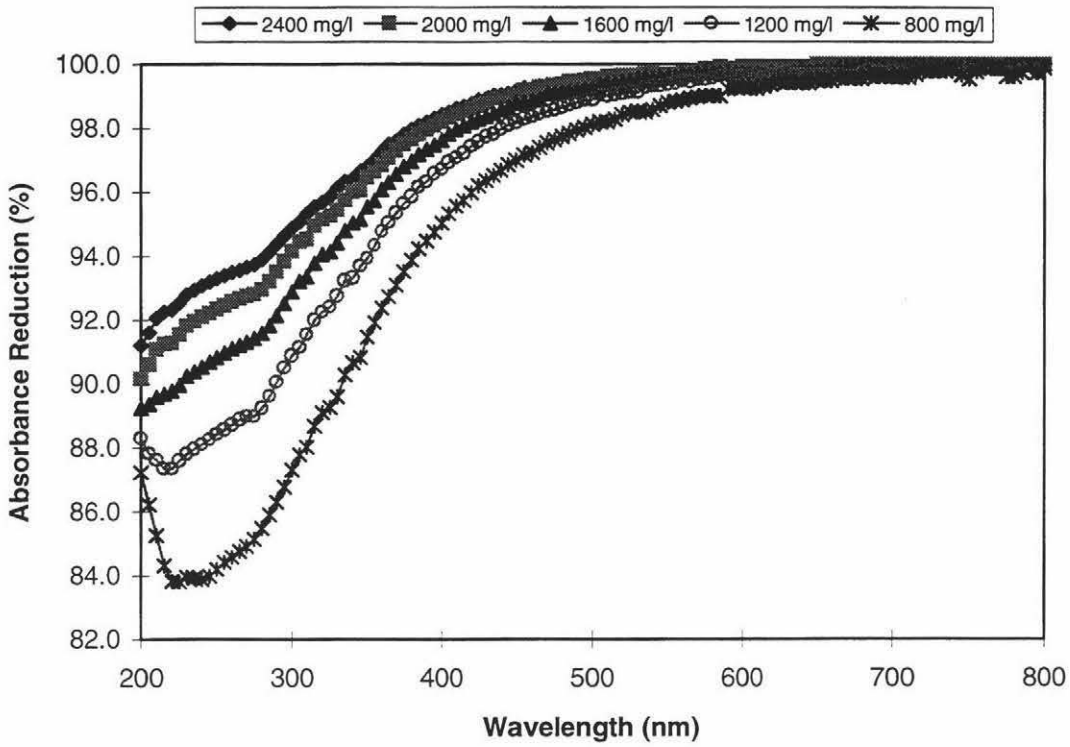

Figure 4-26 Absorbance reduction of pond treated wastewaters after alum coagulation and 0.45 micron filtration treatment

From **Figure 4-26** , it can be seen that alum coagulation followed by 0.45 micron filtration removed 84% to 93.9% of the absorbance in the UV range at an alum dose of 800 mg/l. This removal percentage increased to 99.9% at 800 nm wavelength. Higher alum doses removed more absorbance throughout the spectrum.

4.3.3 Absorbance Spectra of Raw and Carbon Adsorbed Pond Effluent

4.3.3.1 Absorbance spectra of alum coagulated and carbon adsorbed wastewaters

The whole absorbance spectra (200 - 800 nm) from wastewaters coagulated by 1600 mg/l alum followed by activated carbon (AC) adsorption treatment were statistically analysed and the following results were obtained.

Carbon adsorption significantly ($P<0.05$) improved wastewater optical quality. The absorbance spectra (200 - 800 nm) were not significantly ($P>0.05$) different between

wastewaters treated by 0.1 and 0.2 g/l AC. Similarly there were no significant (P>0.05) differences between absorbance spectra of wastewaters treated by 0.5 and 1 g/l AC, or by 1 and 2 g/l AC, and by 2 and 3 g/l AC. The absorbance spectrum of wastewaters treated by 0.2 g/l AC was significantly different (P<0.05) from that of wastewaters treated by 0.5 g/l AC (**Table 4-9**).

An identical result was found for the spectra in the UV region (200 - 380 nm) of these wastewaters. However, statistical analysis of the absorbance spectra in the visible light region (380 - 800 nm) revealed that all these absorbance spectra were significantly different (P<0.05).

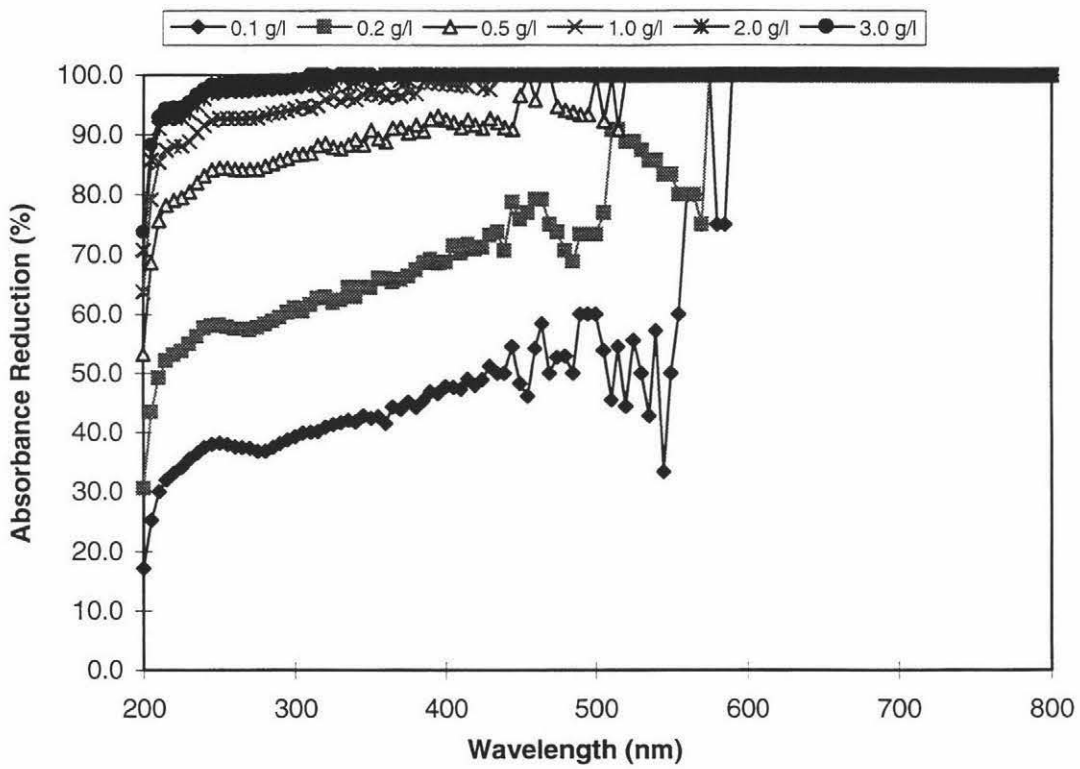

Figure 4-27 Absorbance reduction of 1600 mg/l alum coagulated wastewaters after activated carbon (AC) treatment

Figure 4-27 shows that higher AC dose (2 g/l or more) removed all the absorbance in the visible range and more than 70.7% of the absorbance in the UV range. An AC dose of 0.5 g/l removed 91.6% to 100% of the absorbance in the visible range and more than 53.2% in the UV range. An AC dose of 0.1 g/l removed only less than 45% of the absorbance in the UV range. The fluctuation in the data between 450 and 600 nm was

due to the extremely low absorbance value of the wastewater after alum coagulation treatment.

Table 4-9 Grouping of absorbance spectra (200 - 800 nm) of wastewaters coagulated by 1600 mg/l alum and treated by activated carbon (AC) adsorption.

AC Dose	Statistical Grouping*	
0.0 g/l	A (control)	
0.1 g/l	B	
0.2 g/l	B	
0.5 g/l	C	
1.0 g/l	C	
2.0 g/l	C	D
3.0 g/l	C	D

* Difference in grouping letter shows significant difference in spectra.

4.3.3.2 Absorbance spectra of raw and carbon treated pond effluent

Statistical analysis of the absorbance spectra (200 - 800 nm) of raw and AC treated pond effluent showed that the absorbance spectra of AC treated wastewater were significantly different ($P<0.05$) from that of the raw pond effluent. The spectra were significantly ($P<0.05$) different between wastewaters treated by 1 and 2 g/l AC and by 2 and 10 g/l AC (**Table 4-10**). See **Appendix B-4** for these spectra.

Table 4-10 Grouping of absorbance spectra (200 - 800 nm) of pond treated wastewaters treated by activated carbon (AC) adsorption

AC Dose	Statistical Grouping*	
0.0 g/l	A (control)	
0.5 g/l	B	
1.0 g/l	B	
2.0 g/l	C	
5.0 g/l	C	
10 g/l	C	D

* Difference in grouping letter shows significant difference in spectra.

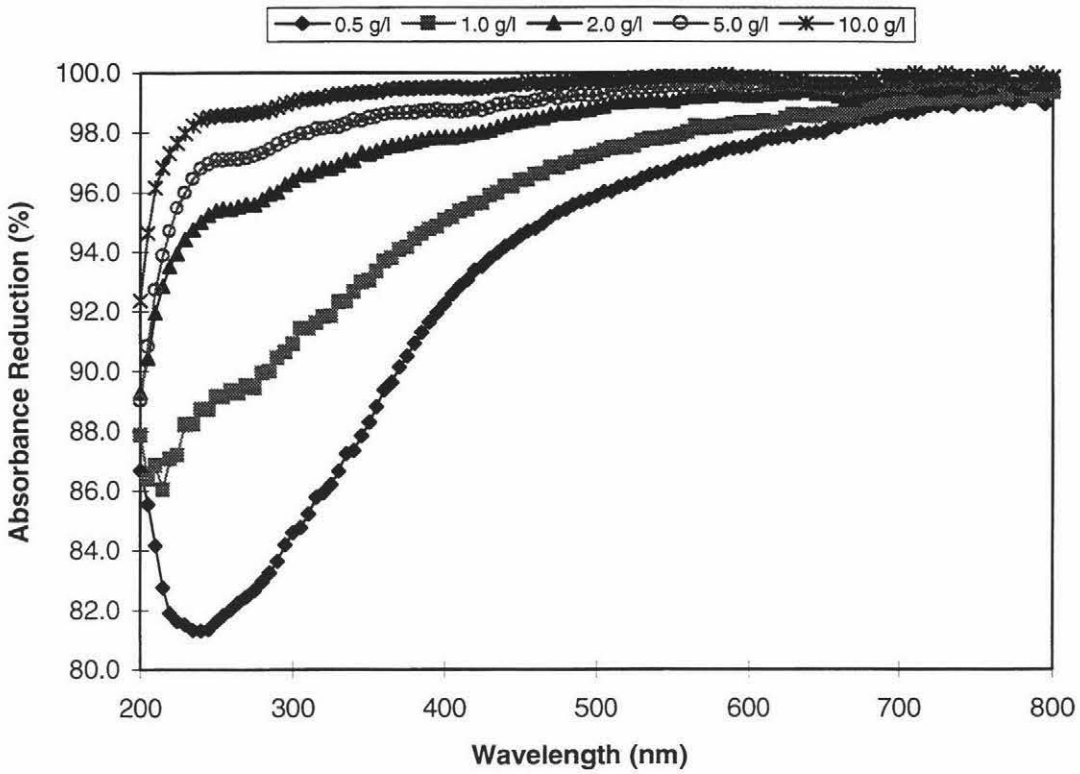

Figure 4-28 Absorbance reduction in pond treated effluent after activated carbon (AC) treatment

Figure 4-28 shows that AC was effective in removing absorbing materials in pond treated wastewater. More than 91% of the absorbance in the visible light range was removed by an AC dose of 0.5 g/l. Coming to the UV range, this removal percentage reduced to 81% at 240 nm. At wavelength of 254 nm, this percentage was less than 82%.

4.3.4 Absorbance Spectra of Wastewaters Treated by Bark and Zeolite

The absorbance spectra of pond treated wastewater treated with 10 g/l zeolite were found significantly different ($P<0.05$) from that of the non treated raw pond effluent. Statistical analysis also showed that there was significant difference ($P<0.05$) between the spectra resulted from 10 g/l zeolite treated (1600 mg/l) alum coagulated wastewater and that from 10 g/l zeolite treated pond effluent (see **Appendix B-5** for these spectra).

The absorbance spectra of both (50 g/l) bark A and (50 g/l) bark B treated pond effluent were significantly different ($P<0.05$) from that of the raw pond effluent. It was also

found that the absorbance spectra resulting from bark A treatment and Bark B treatment were not significantly different (P>0.05).

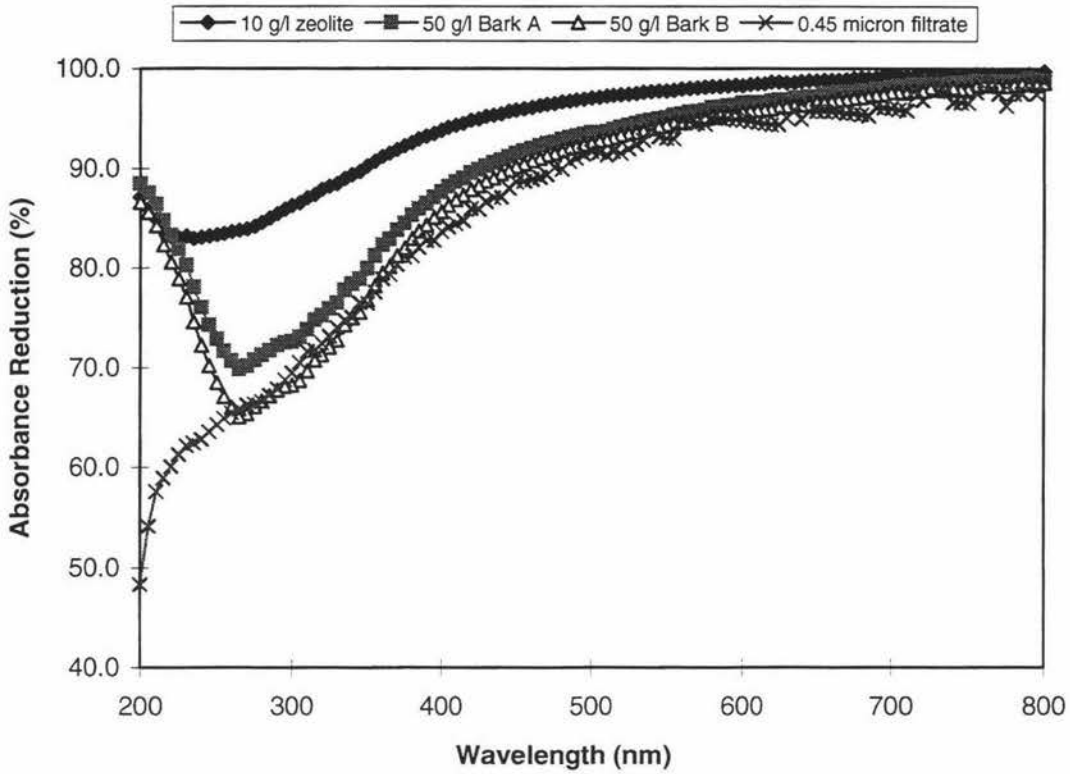

Figure 4-29 Absorbance reduction in pond treated wastewaters after bark and zeolite treatment

Figure 4-29 shows that bark and zeolite treatment followed a similar trend to 0.45 micron filtration treatment in absorbance reduction above 270 nm. 50 g/l bark A and 10 g/l zeolite was more effective than 50 g/l bark B treatment. The interesting finding was that below 270 nm, both bark treatments increased their absorbance removal percentage and these increases continued until about 200 nm.

4.3.5 Summary of the Absorbance Spectra

All the absorbance spectra of the wastewaters before and after treatments were in such a manner that there was neither absorbance peaks nor absorbance valleys. Absorbance on all spectra showed a trend of increased absorbance towards shorter wavelengths. Various treatments (except bark treatment) reduced the absorbance throughout the whole spectra (200 - 800 nm) to some degree. Bark treatment reduced the absorbance

of the raw wastewater in the range below 270 nm, but increased the absorbance of the alum treated wastewater throughout the range (200 - 800 nm).

CHAPTER FIVE

DISCUSSION

5.0 INTRODUCTION

This chapter discusses the experimental results and the possible reasons for such outcomes. Where appropriate, the experimental results are compared with those published ones.

5.1 CHARACTERISTICS OF POND TREATED FARM DAIRY WASTEWATERS

From the farm dairy wastewater sampling results, the following were found in Chapter Four:

- Farm dairy pnd effluent quality parameters change with season and from site to site;
- Farm dairy pond effluent has poorer quality than domestic wastewater and can not be successfully disinfected by UV radiation without prior treatment;

5.1.1 Seasonal Variability of Farm Dairy Wastewaters

From winter (July and August) to summer (December) wastewater characteristics changed with season in Massey No. 4 Farm Dairy pond. Effluent temperature increased from 7.1°C in July to 18.3°C in December. Wastewater temperature was affected by both seasonal and short term (even daily) weather conditions. A 10°C temperature difference would be expected to alter biological growth and reaction rates by about a factor of 2 (Gaudy & Gaudy, 1981) and thus may be expected to alter pond processes. Surprisingly, the seasonal temperature difference was not generally reflected in pond BOD concentrations. From September to December, effluent BOD values (BOD_5, BOD_u and rate constant k) were similar. This finding was consistent with Hickey *et al.* (1989b). One possible explanation for these stable BOD values over season may be that

the effect of increased biological growth and reaction rates due to increased temperature was counteracted by the rise in influent loading rates. A number of factors could be involved in the explanation of these phenomena, for example, oxygen supply may be a limiting factor. However, due to time limitation this could not be proved through continued sampling.

On the contrary, effluent suspended solids (SS), COD and turbidity were affected by the seasonal operation of the farm dairy. Due to the commence of milking season starting in September, these three wastewater quality parameters changed dramatically. SS increased from 131 mg/l in July to 376 mg/l in September and climbed to 489 mg/l in December. COD rose from 478 mg/l in July to over 900 mg/l in September and remained at that level since. Effluent turbidity followed a similar trend, rising sharply from 181 NTU in July to over 500 NTU in September and remained at this level thereafter. These results suggested that these three effluent parameters (COD, SS, and turbidity) were affected by seasonal variability in influent loading (resulting from seasonal milking), or in other words, effluent characteristics for an individual pond were related to seasonal or influent load elevations. This finding was contrary to that suggested by Hickey *et al.* (1989b). One possible reason for this could be that the pond system was going through a "start-up" phase during the monitoring period. It could be reasonably expected that after a certain period of time, the wastewater characteristics would be stabilised, as shown by the results from October to December test.

5.1.2 Site Differences of Farm Dairy Wastewaters

Situated in the same region with similar soil and pasture types, characteristics of wastewater collected from different sites showed great variation. Though the temperatures and pH of wastewaters from different sites were quite similar, other wastewater quality parameters were totally different. Electrical conductivity (EC) varied sixfold, from 386 μS/cm to 2380 μS/cm. Turbidity varied 7 times from 77 NTU to 546 NTU. Suspended solids varied six-fold from 58 to 358 mg/l. COD varied 5 times from 190 to 943 mg/l. The biggest variation in wastewater characteristics was BOD (BOD_5), which varied from 9 mg/l to 148 mg/l. UV absorbance (at 254 nm) varied 4.7 times from

0.17 abs/mm to 0.801 abs/mm. These differences in wastewater characteristics among different sites may be due mainly to the difference in farm management, specifically herd size, treatment system efficiency, and the handling of herds and wastes. For example, the fact that wastewater from Farm B had a significantly lower pH value (7.30) than that from other farms may be due to the dilution by storm water which has lower pH level than general groundwater sources.

5.1.3 Feasibility of UV Disinfection of Raw Farm Dairy Wastewater

Comparing the results in Chapter Four and those in Table 2-4 (Hickey *et al.*, 1989b), it is clear that farm dairy wastewater has poorer quality than domestic wastewater. UV disinfection could not be successfully applied to raw farm dairy pond effluent. The UV (254 nm) transmittance through pond treated wastewater from Massey No. 4 Dairy Farm pond remained zero (abs/cm) over the monitoring period. Wastewater from other farm dairies showed varying degree of UV penetration, however, the best of them (wastewater from Farm Dairy B) offered only a UV transmittance (at 254 nm) of about 2%/cm (transmittance 67.7%/mm and absorbance 0.170 abs/mm in **Table 4-3**). From these results, it could be predicted that the required 60%/cm UV transmittance for effective disinfection could never be reached by the natural processes in the dairy ponds.

After reviewing the published data on the characteristics of effluent from both domestic and dairy shed oxidation ponds in New Zealand (Hickey *et al.*, 1989a and 1989b) and comparing them with the recommended values by Stover *et al.* (1986) for UV disinfection, it is clear that dairy wastewaters have much lower quality than domestic effluents and can not be disinfected by UV radiation without further treatment.

5.1.4 Trend in Farm Dairy Pond Effluent Quality

Effluent quality parameters showed various changes in the farm dairy ponds. In the seven ponds sampled in October 1997, suspended solids concentration averaged 236 mg/l, which is higher than that reported by Hickey *et al.* (1989b) of 197 mg/l. The mean

BOD concentration was 87 mg/l, which was about the same as reported in Hickey *et al.* (1989b) of 88 mg/l.

Effluent quality in the Massey No. 4 Dairy Farm remained nearly the same as four years ago. The mean COD and SS concentration of 809 and 317 mg/l were slightly lower than that reported by Mason (1994) of 884 and 364 mg/l. Considering the increased herd size (from 450 to 500 cows) the two-pond system in Massey No. 4 Dairy farm was still working effectively in breaking down organic wastes.

5.2 CHARACTERISTICS OF FARM DAIRY WASTEWATER AFTER TREATMENT

Experimental results in Chapter Four showed that the nature of farm dairy wastewater was modified through various treatment except dilution.

5.2.1 Dilution Treatment

Regardless of the dilution level, the resultant UV absorbance was consistently proportional to the dilution. The linear regression coefficient (R) for UV absorbance between different dilutions was consistently higher than 0.986645 (**Table 4-5 (a)**). Since the p value were 0.0001 for all dilutions. This means UV absorbance will decrease proportionally when diluted.

Dilution treatment reduced proportionally wastewater COD and turbidity too. The lower correlation coefficient (R^2) in very diluted (0.05 and 0.01) wastewaters could be explained by the low accuracy of COD tests in low concentrations. Considering the COD levels (3 - 48 mg/l) for the samples diluted to 0.05 and 0.01 of their original concentration, the standard deviation of the COD tests (17 - 20 mg/l @ a mean COD of around 200 mg/l, Standard Methods, 1995) significantly affected the accuracy of the COD testing method. Similarly, the lower correlation coefficient (R^2) in very diluted fine filtrates (0.45 and 0.22 micron) was due to the low sensitivity of the turbidity meters below 1 NTU. Factors affecting the precision of the turbidity reading as described in

Standard Methods (1995) might be responsible for the low accuracy of the turbidity tests especially at low turbidity levels.

Because of the linear relationship between wastewater COD and UV absorbance as determine in Chapter 4, the measurement of UV absorbance could be used to estimate the COD of the wastewaters after the calibration curve was obtained. UV absorbance measurement was far more simple than the COD test.

Due to the unstable linear relationship between turbidity and UV absorbance, especially in the treated wastewaters, it is not wise to estimate turbidity by absorbance tests.

Though dilution decreased UV absorbance of wastewaters proportionally and increased UV transmittance exponentially, as discussed in Chapter Four, due to the high dilution factors needed (25 for raw wastewater, 13 for 1.2 micron filtrate and 7 for 0.45 and 0.22 micron filtrate) to reach the required 60%/cm transmittance for effective UV disinfection, dilution alone was not practical for pre-treatment for the application of UV disinfection.

5.2.2 Filtration Treatment

By passing through 1.2 micron filter, wastewater UV absorbance was significantly reduced. Wastewater COD level was significantly reduced by 1.2 micron filtration too. Further filtration through 0.45 and 0.22 micron filters continued to improve UV transmission and reduce COD concentration. The differences in UV transmittance and COD concentration in the 0.45 micron and 0.22 micron filtrates were not statistically significant ($P>0.05$).

Filtration treatment revealed that filtering wastewater through 1.2 micron filter removed nearly half the COD concentration and 80 percent of the turbidity. Particulates removed by further filtration through 0.45 micron contributed 15 percent of the total COD and 10 percent of the total turbidity of the raw wastewater. Colloidal material with particle size

between 0.22 and 0.45 micron constituted of only 2.6% of the COD but 5.4% of the turbidity of the raw wastewater.

According to Metcalf & Eddy (1991), organic contaminants in the size range of 0.22 to 0.45 micron in wastewater comprise bacteria, viruses, cell fragments and some DNA molecules. Organic contaminants in the size range of 0.45 to 1.2 micron consist of part of the algae and protozoa, most of the bacteria and bacterial flocs, and organic debris. Particulates greater than 1.2 micron include part of the algae and protozoa, some of bacterial flocs, and part of the organic debris. Organic materials passing through 0.22 micron filter include synthetic organic compounds, fuvic acids, humic acids, nutrients, RNA molecules, chlorophyll, carbohydrates, polysaccharides proteins, amino acids, vitamins, fatty acids, exocellular enzyme, as well as parts of cell fragments and viruses.

Generally speaking, COD concentration is a measure of the organic matter content present in the wastewater. However, due to the differences in size, shape, and refractive index of the particles which affect the light scattering properties of the wastewater, it is difficult to correlate turbidity with the weight or particle number concentration of the suspended matter (Standard Methods, 1995).

Because the highest UV (254 nm) transmittance achieved in all the filtration test in the monitoring period was less than 3%/cm, the effect of filtration in improving UV penetration was limited. In a previous study, Flowerday (1997) achieved 2.0%/cm UV transmittance through 0.22 micron filtration treatment of the wastewater from the same pond outlet. He concluded that filtration of the wastewater had little effect on UV transmittance. It could be reasonable to suggest that filtration treatment alone could not achieve the required UV transmission for effective UV disinfection of the farm dairy wastewaters.

5.2.3 Coagulation Followed by (0.45 μm) Filtration

Aluminium sulphate was proved to be more effective than zinc sulphate in coagulating colloidal particles to improve wastewater quality. At equivalent cation dose of 0.007

N/L (used successfully by Mamais *et al.*, 1993), aluminium sulphate solution improved farm dairy wastewater UV transmittance to 28.5%/cm, while zinc sulphate increased UV transmittance to only 11.4%. This is not surprising at all, because Mancy *et al.* (1973) have concluded that cations with charges of 3^+ seem to be more effective in replacing adsorbed negative charges. Other cations with charges of 3^+, such as Fe^{3+} and Cr^{3+} either add colour or are expensive, or even poisonous. Mancy *et al.* (1973) have recommended the use of aluminium sulphate as the sole coagulant for the removal of organic matters in solution.

Aluminium sulphate coagulation treatment significantly ($P<0.05$) reduced COD concentration of the wastewaters. COD levels reduced from 638 mg/l in raw wastewater to 172 mg/l in the coagulated sample after 1600 mg/l alum coagulation in the August test, reduced by 73%. As discussed earlier, particulates greater than 0.45 micron contributed to about 65% of the COD, while those between 0.45 and 0.22 micron contributed to another 2.6% of the COD in the wastewater. This may suggest that the reduction in COD concentration after coagulation (and 0.45 micron filtration) was achieved mainly by removing the particulates which constituted a major part of the COD concentration. The total amount of particulates removed by 0.22 micron filtration contributed less than 68% of the total COD without coagulation treatment, while with alum coagulation this removal percentage increased to 73%. This may suggest that a certain amount of particulate matter with a particle size smaller than 0.22 micron was coagulated and removed in the process.

Turbidity was greatly reduced by aluminium sulphate coagulation treatment. Wastewater turbidity was reduced from more than 400 NTU to less than 7 NTU by aluminium sulphate dose of 200 mg/l. However, the effect of aluminium sulphate dose in reducing turbidity slowed down with continued increase in aluminium sulphate dose. For example, aluminium sulphate dose of 1600 mg/l reduced the turbidity level to about 0.3 NTU. Recall that the best UV transmittance after alum coagulation treatment was less than 30%/cm, coagulation treatment alone can not achieve the required UV transmittance for effective disinfection.

Coagulation of farm dairy wastewaters by aluminium sulphate (alum) solution followed by 0.45 micron filtration proved effective in improving UV transmission of the wastewaters too. For the Massey No. 4 Dairy Farm samples, an aluminium sulphate dose of 2400 mg/l was found to improve wastewater quality the most. It is likely that below this dosage, colloidal materials could not be coagulated completely due to the residual negative charges of the organic particles, while beyond this level, excessive Al^{3+} ions keep the flocs suspended instead of settling. However, due to the differences in the characteristics of the wastewaters from different sites (and possibly in different seasons) the optimum aluminium sulphate dose may very from site to site and probably from season to season.

When aluminium sulphate is used to coagulate colloidal materials, it must be mixed rapidly into the wastewater, to give it a chance to contact colloidal materials before it reacts with OH^- or water. Once the colloids are coagulated, the flocs must be stirred gently (flocculation) or not be disturbed so that they may settle quickly and thoroughly.

Experimental results on the coagulation of Massey No. 4 samples showed that there was no significant difference among wastewater characteristics resulted from stirring time of 1, 2 and 5 minutes. UV transmittance was significantly lower for coagulated wastewaters stirred for 30 minutes and 1440 minutes. Prolonged stirring time of 1440 minutes provided the lowest UV transmittance among the coagulation stirring duration tests. Settling time after aluminium sulphate coagulation was found to play a role in improving UV transmission at prolonged stirring durations. At short stirring durations the differences of UV transmittance at different settling time were not significant ($P>0.05$).

Experimental results on the coagulation of wastewaters from other farm dairies also showed that there were significant difference in UV transmittance between settling time of 2 hours and settling time of 24 hours.

The best UV transmittance achieved by aluminium sulphate coagulation was about 29%/cm on wastewater samples from Massey No. 4 Dairy farm. No wastewater samples

from other farm dairies achieved the required 60%/cm transmittance for effective UV disinfection after aluminium sulphate coagulation followed by 0.45 micron filtration treatment, though some wastewaters provided more than 50%/cm UV transmittance after these treatments.

5.2.4 Ultracentrifugation

Experimental results showed that after 1600 mg/l alum coagulation and 0.45 micron filtration treatment ultracentrifugation at 105,000 g for one hour did not significantly improve wastewater UV transmission. This is possibly due to the fact that there were very few particulates left in the aluminium sulphate coagulated and filtered sample (this was so because the turbidity level in the sample was as low as less than one), and that these particulates contributed to the UV absorbance (including scattering) only insignificantly. However, it is imaginable that at much lower aluminium sulphate dose or without filtration, ultracentrifugation may help improve wastewater UV transmission to some extent.

Ultracentrifugation at 105,000 g for one hour may remove particulates with molecular weight of between 10^6 to 10^7 amu (J.W. Tweedie, pers. Comm., Department of Biochemistry, Massey University). This corresponds to a particle size of 10^{-2} to 10^{-1} μm in Metcalf & Eddy (1991). It may be speculated that this ultracentrifugation may have removed part of the proteins, part of the polysaccharides, most of the viruses, and nearly all the cell fragments. Of course, particles greater than these sizes are all removed in this ultracentrifugation treatment.

Theoretically, all the particulates will be removed if ultracentrifugation forces is increased and the duration prolonged to a certain level. However, it must be noted that the high cost and low treatment capacity of the ultracentrifuge made ultracentrifugation treatment a research tool only. Becuase of the time limitation, more detailed study of the effect of ultracentrifugation process on wastewater characteristics was not carried out.

5.2.5 Oxidation by Hydrogen Peroxide

The addition of hydrogen peroxide into wastewater (pre-treated by 1600 mg/l aluminium sulphate followed by 0.45 micron filtration) deteriorated UV transmission immediately after dosing. Though UV transmittance regained gradually, it never restored to the level before dosing. The reason is that hydrogen peroxide itself is a strong UV (254 nm) absorbing material and the residual hydrogen peroxide contributed to the reduction in UV transmittance in higher hydrogen peroxide dose treatment. In lower hydrogen peroxide dose treatment, though some organic matter was broken down by hydrogen peroxide, big particles were broken into more small particulates which contributed to turbidity and UV absorption. These small particulates were continued to be oxidized which resulted in the recovery in UV transmission with time. But the reason why even after seven days UV transmittance could not recover to the level before the hydrogen peroxide dosing was not known. One possibility may be that the oxidation product was also UV (254 nm) absorbing material(s). The nature of the oxidation product(s) should be investigated in further studies.

Due to the slow reaction rate and the possibility of residual hydrogen peroxide, wastewater treatment by hydrogen peroxide could not be recommended for improving UV transmission through wastewater. However, hydrogen peroxide itself is a disinfectant, and was used by Flowerday (1997) to disinfect dairy shed wastewater.

5.2.6 Adsorption

5.2.6.1 Activated carbon (AC) treatment

Activated carbon (AC) was effective in improving UV transmission in both raw and aluminium sulphate coagulated wastewaters. The effectiveness of AC was much higher in the aluminium sulphate coagulated wastewaters. The possible reason for this is that in treating raw wastewater substantial amount of the adsorption sites were used by the suspended solids and particulates, while in treating the aluminium sulphate treated

filtrates, nearly all the adsorption site was available for the removal of colloidal and dissolved organic matter.

The required 60%/cm UV (254 nm) transmittance for effective UV disinfection was achieved by 0.5 g/l AC on aluminium sulphate treated samples and 5.0 g/l Ac on raw wastewaters.

5.2.6.2 Bark treatment

Bark A was effective in improving raw wastewater UV (254 nm) transmission. UV transmittance (at 254 nm) increased from 0.3%/cm to 0.7%/cm after adsorption treatment by 50 g/l Bark A. Bark B was ineffective in treating raw wastewater because UV transmittance remained the same after 50 g/l Bark B treatment for one day.

Both Bark A and Bark B reduced the UV (254 nm) transmittance through the aluminium sulphate coagulated wastewater. Bark A reduced UV transmittance from 20.3%/cm to 5%/cm while bark B reduced UV transmittance to 2.6%/cm.

Due to the poor performance of bark in improving wastewater UV transmission, it may not be suitable to be used for further study in the UV disinfection research.

5.2.6.3 Zeolite treatment

Zeolite was effective in improving raw pond effluent UV transmission but ineffective in treating the aluminium sulphate coagulated samples. Zeolite dose of 10 g/l improved raw wastewater UV (254 nm) transmittance from 0 to 5.4%/cm. The role of zeolite here was more likely as a coagulant than as an adsorption agent. Considering the zeolite dose (10 g/l) in the experiment, this treatment technology was doubtful of practical use.

5.2.6.4 Reaction time and dose in adsorption treatment

The reaction in the adsorption treatment by activated carbon (AC) was quicker in high AC doses (e.g., 5 g/l). At lower AC dose levels (i.e., 0.2 g/l), reaction continued even to the fifth day.

5.3 ABSORBANCE SPECTRA OF WASTEWATERS

5.3.1 Raw Farm Dairy Wastewaters

The absorbance spectra of raw and filtered farm dairy wastewater form Massey No. 4 Dairy Farm are shown in **Appendix B-1**. These were spectra with a continued increase in absorbance down to shorter wavelengths. A shoulder existed in each spectrum below 300 nm followed by quick increase in absorbance below about 250 nm. The reduction in absorbance after filtration through 1.2 micron filter may be resulted from the decrease of light scattering caused by particulates greater than 1 micron. This may be speculated from Stover *et al.* (1986) in which they believed that by passing through 1 micron filter the absorbance is approximate to the true absorbance of the wastewater. There were no absorbance peaks or valleys in these raw wastewater absorbance spectra, implying that there was no specific organic material dominating in the wastewaters. The absorbance spectrum was contributed by organic compounds of diverse nature and low concentrations which comprise the total dissolved organic matter in the farm dairy wastewaters. The absorbance spectra in the UV range was similar to that of natural waters reported by Foster and Morris (1974) except that the absorbance through farm dairy wastewaters are much higher than that of the natural waters.

As reported by Foster and Morris (1974), at wavelengths below 250 nm, both inorganic and organic species contribute to the absorbance of natural waters, whereas above this wavelength, only organic materials strongly absorb. Ogura and Hanya (1966, 1967) found in studying sea water that dissolved organic matter contributed only a small fraction of the total absorbance below 230 nm, but was predominant at longer wavelengths. They found that the only effective inorganic species were nitrate and

bromide, the absorbance of both being particularly apparent at wavelengths below 235 nm. From these it can be suspected that the higher absorbance of farm dairy wastewaters below 235 nm was contributed possibly by nitrate.

5.3.2 Aluminium Sulphate Coagulated Farm Dairy Wastewaters

Alum treatment at 1600 mg/l dose removed more than 93.9% of the absorbance in the visible light range. Down to the UV range (380 - 200 nm), the absorbance reduction percentage became lower and lower. The shape of the spectra was quite similar to that of the raw wastewater except that the absorbance value was reduced. This showed that aluminium sulphate coagulation had no preference in removing absorbing organic matter. The sharp increase in absorbance below 235 nm may imply the existence of nitrate, on which aluminium sulphate coagulation had no effect.

5.3.3 Activated Carbon (AC) Treated Farm Dairy Wastewaters

The absorbance spectra from both AC treated raw wastewater (**Appendix B-3**) and AC treated alum-coagulated wastewater (**Appendix B-4**) had a similar pattern. Due to the removal of materials by the aluminium sulphate coagulation process, the absorbance spectra of AC treated alum-coagulated wastewater was much lower. In the UV range, the effectiveness of AC in reducing absorbance became lower. The effectiveness of AC reduced sharply below about 250 nm. This may imply that AC removed the fraction of absorbance contributed by only organic material, while the inorganic species, such as nitrate and ammonium, were still absorbing. More tests are needed to verify this.

5.3.4 Bark and Zeolite Treated Farm Dairy Wastewaters

As shown in **Appendix B-5 and Appendix B-6**, bark and zeolite treatment increased the absorbance of the alum-coagulated 0.45 micron filtered wastewaters but decreased the absorbance of the raw wastewaters. These results implied that bark treatment increased the organic matter concentration in the alum-coagulated and 0.45 micron filtered wastewaters. In the visible light range (380-800 nm) bark treatment had no

effect on raw wastewater absorbance spectra (as the spectra followed the same line of that from 0.45 micron filtration). However, below 270 nm, bark treatment greatly reduced the absorbance of the raw wastewater. The absorbance spectrum levelled below 270 nm. This may imply the removal of nitrate and ammonium through adsorption by bark.

The existence of inorganic species such as nitrate and ammonium was confirmed by Bolan *et al.* (1996). They reported that the concentrations of nitrate and ammonium in the second pond effluent of Massey No. 4 Dairy Farm were 15 and 95 mg/l respectively. The absorbance spectrum contributed by these concentrations of nitrate and ammonium was simulated in **Figure 5-1**. It was found that nitrate absorbed much more strongly than ammonium. The combined absorbance spectrum by 15 mg/l nitrate and 95 mg/l ammonium was nearly overlapped with the absorbance spectrum by 15 mg/l nitrate over most of the wavelengths except those below 204 nm. The 95 mg/l ammonium concentration contributed 0.003 abs/cm over the wavelength between 206 and 270 nm. From this it can be concluded that the sudden great reduction in absorbance spectrum below 240 nm in bark treatment was by the removal of nitrate from the wastewater. However, **Figure 5-1** also showed that at 254 nm, 15 mg/l nitrate and 15 mg/l ammonium together contributed only 0.005%/cm of the total absorbance. This 0.005%/cm absorbance corresponded to 98.9%/cm of UV transmittance. So it must be noted that the removal of nitrate and ammonium from the wastewater by bark and zeolite did not improve UV transmission at 254 nm greatly.

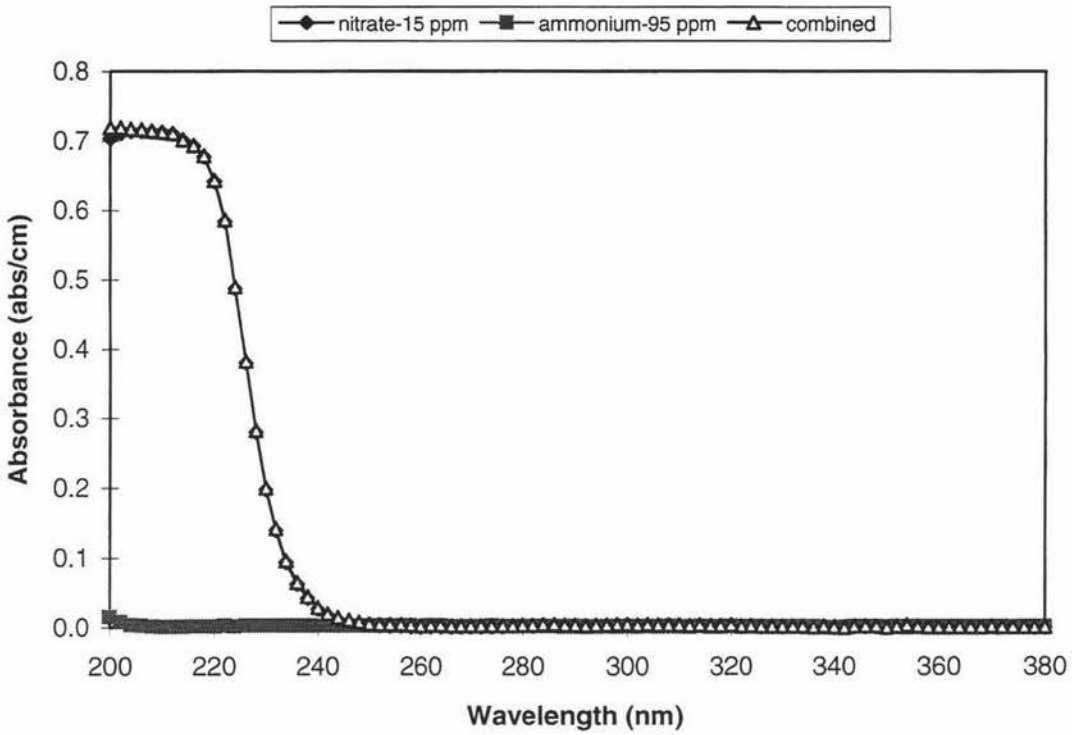

Figure 5-1 Absorbance spectra of (15 mg/l) nitrate and (95 mg/l) ammonium as well as the combined spectrum by (15 mg/l) nitrate and (95 mg/l) ammonium

There is no published paper confirming the removal of nitrate by bark treatment at this time. However, nitrate removal mechanism may include the contact of nitrate with bark material and the removal of it through microbiological reactions (Bolan, Pers. comm., Department of Soil Science, Massey University, 1998).

Through the discussion in Section 5.3.1 to Section 5.3.4, it can be concluded that farm dairy wastewater absorbance spectra showed a continued increase in absorbance down to the shorter wavelengths. No specific material was dominant in the wastewaters. Filtration treatment removed organic materials and reduced the absorbance over the whole spectral range of 200 to 800 nm. Aluminium sulphate coagulation treatment removed the particulates and some dissolved organic matter and by doing so greatly improved the optical quality of the wastewaters. Activated carbon was very effective in removing the organic matter in the effluent. Bark and zeolite treatments were useful only in reducing the absorbance of raw wastewaters. Bark was very good in reducing UV absorbance below 250 nm wavelengths by adsorbing and removing nitrate and ammonium. Other material (AC, aluminium sulphate) was ineffective in reducing nitrate.

Aluminium sulphate coagulation and carbon adsorption treatment were excellent in removing absorbance in the visible light range thus are good techniques in wastewater decolourisation.

5.4 RESEARCH LIMITATIONS AND FURTHER RESEARCH

This research was conducted on a bench-scale only. Most of the results were obtained on the Massey No. 4 Farm Dairy samples. Due to the time and financial limitations, wastewater from six other farm dairies were sampled only once. A larger number of sampling sites and more frequent sampling are needed to monitor the wastewater quality variation over time and among farm dairies. Due to the time limitation a preferred annual monitoring of wastewaters was not possible in this study. Repetitions and treatment levels and factors considered in the experimental work were limited.

Further research into the use of UV radiation to disinfect farm dairy wastewater should include:

- A larger number of sampling sites, including wastewater from tertiary treatment processes to aquire more information on the characteristic of the farm dairy wastewater and their suitability for UV disinfection;
- Longer sampling period, preferably one year or longer to characterise the annual changes of the wastewater quality;
- Pilot scale testing if possible to verify the finding from this bench-scale research;
- Combination of treatment technologies for better removal of waste materials, especially the dissolved material(s);
- Further investigation into the nature of the residual waste material(s) absorbing UV radiation.

CHAPTER SIX
CONCLUSIONS

Farm dairy wastewater disinfection may be needed for either wastewater reclamation, reuse or discharging into the natural waterways. Ultraviolet irradiation provides one of the best alternatives for wastewater disinfection. A minimum of 60% UV transmittance per centimetre was mentioned in literature and some manufacturer manuals for UV disinfection applications.

Wastewaters from the farm dairies are of poorer quality than domestic sewage and can not be disinfected successfully by UV radiation without prior treatment. Pond treated farm dairy wastewater UV transmittance through 1 cm quartz cell at 254 nm was zero. Wastewater from Massey No. 4 Dairy Farm pond had a COD of 809 mg/l, suspended solids of 317mg/l, turbidity of 450 NTU, and BOD_5 of 150 mg/l.

The quality of farm dairy wastewaters changed with season. Effluent suspended solids (SS), COD, and turbidity were affected by influent loading. With the commencing of milking season, SS increased from 131 mg/l in July to 376 mg/l in September. In the same period, COD increased from 478 mg/l to over 900 mg/l, while turbidity climbed from 181 NTU to over 500 NTU. However, wastewater BOD values were similar over the monitoring period.

With the exception of temperature and pH, wastewater quality parameters monitored showed great variation from site to site. Electrical conductivity varied from 386 to 2380 µS/cm. Turbidity varied from 77 NTU to 546 NTU. SS varied from 58 to 358 mg/l. COD varied from 190 to 943 mg/l. BOD showed the biggest site variation, from 9 mg/l to 148 mg/l. UV absorbance at 254 nm varied between 0.17 and 0.801 abs/cm.

Filtration through 1.2 micron filter removed the suspended solids which contributed to nearly half the COD and 80% of the turbidity, and slightly improve UV penetration. In most cases, wastewater UV (254 nm) transmittance remained zero after this treatment.

Filtration through 0.45 and 0.22 micron filter further improved wastewater quality but this improvement was limited. Particulates in the size range between 1.2 and 0.45 micron constituted 15% of the COD and 10% of the turbidity of the raw wastewater. Particulates between 0.45 and 0.22 micron contributed to 2.6% of the COD and 5.4% of the turbidity of the raw wastewater. Wastewater UV transmittance was less than 1% per centimetre after these filtrations. There was no significant UV transmission improvement by filtering the 0.45 micron filtrate through 0.22 micron filters.

Alum coagulation followed by 0.45 micron filtration treatment removed not only the particulates greater than 0.45 micron, but also some colloidal material smaller than 0.45 and 0.22 micron. Turbidity level reduced from more than 400 NTU in raw pond effluent to less than 7 NTU after 200 mg/l alum coagulation treatment. However, turbidity persisted even in 1600 mg/l alum treated wastewater. alum coagulation followed by 0.45 micron filtration resulted in significant improvement in UV penetration, but the required 60% transmittance was not reached. The best optical quality achieved in the testing season on the Massey No. 4 samples was about 30%/cm transmittance (at 254 nm).

Activated carbon (AC) adsorption treatment was very effective in improving wastewater optical quality. AC was more efficient in treating alum coagulated wastewaters. To reach 60%/cm UV transmittance (at 254 nm) AC dose of 0.5 g/l and 5 g/l were needed for (1600 mg/l) aluminium sulphate treated and raw wastewater accordingly.

Ultracentrifugation at 105,000 g for one hour may have removed particulates greater than 10^7 to 10^6 amu and 10^{-2} to 10^{-1} μm, including part of the proteins, polysaccharides, most of the viruses, and nearly all the cell fragments.

Adsorption treatment by bark and zeolite improved UV penetration in raw pond effluent. Bark treatment greatly reduced UV absorbance below 250 nm which might be contributed by nitrate and ammonium. However, Bark treatment could not greatly improve UV transmission at 254 nm.

Hydrogen peroxide oxidation treatment was not suitable for improving wastewater UV transmission. Hydrogen peroxide itself is a strong absorbing material at 254 nm. However, hydrogen peroxide itself could be used as a disinfectant.

Strong correlation existed between wastewater COD and UV absorbance (at 254 nm). UV absorbance tests may be used to estimate COD levels of wastewaters. Calibration of the COD-absorbance relationship for each wastewater is needed.

A combination of treatment techniques may be pursued to find the most suitable treatment technologies in treating farm dairy wastewaters for UV disinfection.

Further study is needed to find the nature of residual (dissolved) UV absorbing material(s) and provide further information for the application of UV disinfection of farm dairy wastewater.

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APPENDIX A-1
EXPERIMENTAL DATA - JULY TEST

UV Disinfection Experiment III --- 9 am 17/07/1997

Monitoring Results

Temperature: 7.1 C
Turbidity:181 NTU
Electrical Conductivity: 2049 micrometer/cm
Suspended Solids (total): 154/112 mg/l or 133 mg/l

COD & Transmittance/Absorbance Test Results

Transmittance through 10 mm quartz cell at 254 nm (%) - Replicates

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.0	0.7	13.4	35.3	58.2	89.1
1.2 micron filtrate	0.2	5.4	32.2	58.5	75.7	93.3
0.45 micron filtrate	2.2	15.0	47.8	69.7	84.7	97.3
0.22 micron filtrate	2.6	16.5	49.3	70.8	84.7	97.3
Raw pond effluent	0.0	0.7	13.4	35.5	53.3	89.9
1.2 micron filtrate	0.2	5.4	32.4	58.2	75.7	93.3
0.45 micron filtrate	2.2	15.0	47.8	70.3	84.7	97.3
0.22 micron filtrate	2.6	16.7	49.1	70.8	85.1	97.3

Zinc coagulated filtrate (A)	11.4	**Note: (A)= 1000 mg/l zinc sulphate, pH=10.5**
Alum coagulated filtrate (B)	20.2	**(B)= 1550 mg/l alum sulphate, pH=10.5**
Alum coagulated filtrate (C)	31.8	**(C)= 1550 mg/l alum sulphate, pH=4.5**
Alum coagulated filtrate (D)	28.5	**(D)= 773 mg/l alum sulphate, pH=4.5**

Transmittance through 10 mm quartz cell at 254 nm (%) - Average

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.0	0.7	13.4	35.4	55.7	89.5
1.2 micron filtrate	0.2	5.4	32.3	58.3	75.7	93.3
0.45 micron filtrate	2.2	15.0	47.8	70.0	84.7	97.3
0.22 micron filtrate	2.6	16.6	49.2	70.8	84.9	97.3

Absorbance through 10 mm quartz cell at 254 nm - Replicates

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	4.700	2.153	0.874	0.452	0.235	0.050
1.2 micron filtrate	2.698	1.268	0.492	0.233	0.121	0.030
0.45 micron filtrate	1.660	0.825	0.321	0.157	0.072	0.012
0.22 micron filtrate	1.584	0.782	0.307	0.150	0.072	0.012

APPENDIX A-1 (continued)

Raw pond effluent	4.500	2.157	0.872	0.450	0.273	0.046
1.2 micron filtrate	2.700	1.268	0.490	0.235	0.121	0.030
0.45 micron filtrate	1.655	0.823	0.321	0.153	0.072	0.012
0.22 micron filtrate	1.586	0.778	0.309	0.150	0.070	0.012

Zinc coagulated filtrate (A)	0.943
Alum coagulated filtrate (B)	0.695
Alum coagulated filtrate (C)	0.498
Alum coagulated filtrate (D)	0.545

Absorbance through 10 mm quartz cell at 254 nm - Average

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	4.600	2.155	0.873	0.451	0.254	0.048
1.2 micron filtrate	2.699	1.268	0.491	0.234	0.121	0.030
0.45 micron filtrate	1.658	0.824	0.321	0.155	0.072	0.012
0.22 micron filtrate	1.585	0.780	0.308	0.150	0.071	0.012

Absorbance of COD Samples through 10 mm quartz cell at 600 nm

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.155	0.085	0.054	0.033	0.022	0.015
1.2 micron filtrate	0.102	0.061	0.030	0.022	0.019	0.017
0.45 micron filtrate	0.074	0.051	0.028	0.018	0.014	0.012
0.22 micron filtrate	0.071	0.037	0.025	0.016	0.011	0.012
Raw pond effluent	0.159	0.087	0.053	0.031	0.020	0.013
1.2 micron filtrate	0.102	0.058	0.028	0.016	0.019	0.015
0.45 micron filtrate	0.070	0.048	0.025	0.016	0.012	0.012
0.22 micron filtrate	0.069	0.034	0.027	0.014	0.012	0.012

Zinc coagulated filtrate (A)	0.054
Alum coagulated filtrate (B)	0.028
Alum coagulated filtrate (C)	0.025
Alum coagulated filtrate (D)	0.019

Note: 5Standard@ 0.164
5Blank@ 0.010

COD Concentration - replicates

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	470	245	143	75	40	15
1.2 micron filtrate	298	165	66	39	30	22
0.45 micron filtrate	208	132	59	27	13	6
0.22 micron filtrate	198	88	50	18	3	6
Raw pond effluent	485	250	138	69	31	10
1.2 micron filtrate	300	155	58	20	28	15
0.45 micron filtrate	195	123	50	20	6	7
0.22 micron filtrate	190	79	54	14	6	7

Zinc coagulated filtrate (A)	175.3
Alum coagulated filtrate (B)	90.9
Alum coagulated filtrate (C)	81.2
Alum coagulated filtrate (D)	61.7

APPENDIX A-1 (continued)

	COD Concentration - Average					
Dilution	5	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	478	248	141	72	36	13
1.2 micron filtrate	299	160	62	30	29	19
0.45 micron filtrate	202	128	55	24	10	7
0.22 micron filtrate	194	84	52	16	5	7

UV Absorbance vs Cell Path Length Test Results ---15/07/1997

Wastewater Cell Path Length (cm)

	1.0	0.2	0.1
Raw pond effluent	4.532	0.908	0.484
1.2 micron filtrate	2.657	0.547	0.300
0.45 micron filtrate	1.663	0.338	0.180
0.22 micron filtrate	1.593	0.321	0.171

APPENDIX A-2
EXPERIMENTAL DATA - AUGUST TEST

UV Disinfection Experiment III --- 9 am 19/08/1997

Monitoring Results

Temperature: 13.5 C
Turbidity:400 NTU
Electrical Conductivity: 2333 microsimens/cm
Suspended Solids (total): 190, 196, 200 mg/l, or 195 mg/l in average

COD & Transmittance/Absorbance Test Results

Transmittance through 10 mm quartz cell at 254 nm (%)

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.0	0.3	8.4	29.4	55.8	91.9
1.2 micron filtrate	0.1	3.8	29.1	55.6	76.2	96.3
0.45 micron filtrate	0.7	11.0	44.2	68.1	84	98.4
0.22 micron filtrate	1.1	13.4	45.6	68.8	84.7	98.5

Absorbance through 10 mm quartz cell at 254 nm - calculated

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	4.600	2.523	1.076	0.532	0.253	0.037
1.2 micron filtrate	3.000	1.420	0.536	0.255	0.118	0.016
0.45 micron filtrate	2.155	0.959	0.355	0.167	0.076	0.007
0.22 micron filtrate	1.959	0.873	0.341	0.162	0.072	0.007

Absorbance through 10 mm quartz cell at 254 nm - measured

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	4.600	2.626	1.096	0.552	0.271	0.054
1.2 micron filtrate	2.988	1.437	0.551	0.273	0.134	0.030
0.45 micron filtrate	2.170	0.973	0.371	0.184	0.092	0.021
0.22 micron filtrate	1.989	0.890	0.356	0.179	0.089	0.022

Turbidity - measured

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	400.00	174.00	61.00	29.80	13.60	2.79
1.2 micron filtrate	72.30	28.20	12.00	5.97	3.04	0.78
0.45 micron filtrate	38.30	3.91	1.58	0.93	0.53	0.28
0.22 micron filtrate		1.65	0.62	0.64	0.31	0.19

APPENDIX A-2 (continued)

Absorbance of COD Samples through 10 mm quartz cell at 600 nm

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.232	0.123	0.057	0.034	0.023	0.015
1.2 micron filtrate	0.143	0.069	0.034	0.023	0.017	0.014
0.45 micron filtrate	0.117	0.075	0.030	0.021	0.023	0.014
0.22 micron filtrate	0.115	0.069	0.035	0.022	0.018	0.011
balnk	0.008	0.01	0.012		**Average=0.010**	
standard	0.184	0.191	0.183		**Average=0.184**	

COD Concentration - calculated

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	638	325	135	69	37	14
1.2 micron filtrate	382	170	69	37	20	11
0.45 micron filtrate	307	187	57	32	37	11
0.22 micron filtrate	302	170	72	34	23	3

Coagulated and filtrated Test Results*

Alum dosage (mg/l)	Transmittance	absorbance - 254 nm	Turbidity (NTU)	COD absorbance -adjusted	COD Calculated (mg/l)
200	3.8	1.421	6.39	0.083	259
400	5.9	1.228	4.80	0.078	244
600	9.2	1.037	3.54	0.075	234
800	14.3	0.848	2.76	0.064	200
1000	19.8	0.702	2.00	0.063	197
1200	24.0	0.619	0.93	0.060	188
1400	30.7	0.514	0.33	0.056	175
1600	31.6	0.495	0.27	0.055	172

*Quick mix for 2 min. Settled for 2 hours, filtrated through 0.45 micron filter.

COD sample absorbance for the coagulated and filtered tests

COD Blank absorbance	COD Standard absorbance
0.014	0.166
0.012	0.184
0.014	0.168
Average: 0.013	**0.173**

APPENDIX A-3
EXPERIMENTAL DATA - SEPTEMBER TEST

UV Disinfection Experiment IV --- 9 am 16/09/1997

Monitoring Results

Temperature: 9.2 C
Turbidity: 532 NTU
Electrical Conductivity: 2750 microsimens/cm (Site); 2710 microsimens/cm (Lab, 11 C)
Suspended Solids (Total): 388 mg/l, 366 mg/l, or 376 mg/l in average.

COD & Transmittance/Absorbance Test Results

Transmittance through 10 mm quartz cell at 254 nm (%)

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.0	0.0	5.0	22.6	46.6	86.0
1.2 micron filtrate	0.0	3.2	25.6	51.2	71.6	93.2
0.45 micron filtrate	0.5	8.0	37.4	61.6	78.9	94.1
0.22 micron filtrate	0.8	10.3	41.2	64.7	80.6	94.3

Absorbance through 10 mm quartz cell at 254 nm

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	6.500	3.250	1.301	0.646	0.332	0.066
1.2 micron filtrate	3.000	1.495	0.592	0.291	0.145	0.031
0.45 micron filtrate	2.301	1.097	0.427	0.210	0.103	0.026
0.22 micron filtrate	2.097	0.987	0.385	0.189	0.094	0.025

Turbidity - measured

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	540	218	73.7	35.6	17.2	3.56
1.2 micron filtrate	116	27.5	11.9	6.14	3.27	0.87
0.45 micron filtrate	51.5	4.83	2.06	1.15	0.76	0.39
0.22 micron filtrate	24.0	1.52	0.64	0.58	0.36	0.26

Absorbance of COD samples through 10 mm cell at 600 nm - measured

Dilution	1	0.5	0.2	0.1	0.05	0.01	
Raw pond effluent	0.302	0.154	0.062	0.037	0.021	0.010	
1.2 micron filtrate	0.154	0.077	0.037	0.021	0.014	0.012	
0.45 micron filtrate	0.119	0.058	0.030	0.018	0.012	0.010	
0.22 micron filtrate	0.117	0.063	0.029	0.019	0.012	0.007	
blank	0.006	0.007	0.006				**Average=0.006**
Standard	0.164	0.161	0.158	0.177	0.157		**Average=0.163**

APPENDIX A-3 (continued)

Absorbance of COD samples through 10 mm cell at 600 nm - adjusted

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.296	0.148	0.056	0.031	0.015	0.004
1.2 micron filtrate	0.148	0.071	0.031	0.015	0.008	0.006
0.45 micron filtrate	0.113	0.052	0.024	0.012	0.006	0.004
0.22 micron filtrate	0.111	0.057	0.023	0.013	0.006	0.001

COD concentration - calculated

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	943	471	178	99	48	13
1.2 micron filtrate	471	226	99	48	25	19
0.45 micron filtrate	360	166	76	38	19	13
0.22 micron filtrate	354	182	73	41	19	3

Coagulated and filtrated test results

Alum dosage (mg/l)	transmittance	absorbance	turbidity(NTU)	CODabsorbance	COD (mg/l)
1000	11.0	0.960	0.62	0.064	204
1200	14.8	0.829	0.61	0.055	175
1400	18.0	0.745	0.69	0.054	172
1600	22.6	0.645	0.44	0.054	172
1800	24.7	0.608	0.33	0.051	162
2000	28.2	0.550	0.45	0.045	143

APPENDIX A-3 (continued)

BOD Results

Time (days)	0.45 filtrate	Raw1	Raw2	Raw3	Raw pond effluent	1000 mg/l filtrate	1600 mg/l filtrate	2000 mg/l-1	2000 mg/l-2	2000 mg/l filtrate
0	0	0	0	0	0	0	0	0	0	0
1	25	60	46	52	53	19	7	1	6	4
2	35	85	71	72	76	32	19	13	18	16
3	48	125	103	99	109	47	38	28	33	31
5	65	170	146	134	150	62	49	33	41	37
6	75	188	164	152	168	62	52	38	43	41
7	85	202	176	165	181	66	57	41	46	44
8	98	217	191	179	196	69	58	43	48	46
9	108	227	203	189	206	70	61	47	51	49
10	110	234	211	196	214	71	63	51	53	52
13	110	250	228	212	230	73	67	58	61	60
14		254	236	219	236	73	67	58	61	60
15		260	241	222	241	74	67	59	62	61
17		268	249	228	248	78	67	62	62	62
19		277	257	234	256	80	67	62	62	62

APPENDIX A-4
EXPERIMENTAL DATA - OCTOBER TEST

UV Disinfaction Experiment V---21/10/1997

Monitoring Results

Temperature: 13.5 C
Turbidity: 546 NTU
Electrical Conductivity: 2300microsimens/cm
Supended Solids: 296, 360 mg/l or 328 mg/l in average

COD & Transmittance/ Absorbance Test Results

Transmittance through 10 mm quartz cell at 254 nm(%)

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0	0	4.4	21.7	46.7	85.6
1.2 micron filtrate	0	1.9	20.3	44.6	66.3	91.3
0.45 micron filtrate	0.6	8.6	36.8	60.8	77.3	94.8
0.22 micron filtrate	0.8	9.3	38.2	61.7	78.1	94.6

Absorbance through 10 mm quartz cell at 254 nm

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	6.700	3.350	1.357	0.664	0.331	0.068
1.2 micron filtrate	3.500	1.721	0.693	0.351	0.178	0.040
0.45 micron filtrate	2.222	1.066	0.434	0.216	0.112	0.023
0.22 micron filtrate	2.097	1.032	0.418	0.210	0.107	0.024

Absorbance of COD samples through 10 mm cell at 600 nm - measured

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.302	0.154	0.065	0.034	0.020	0.008
1.2 micron filtrate	0.142	0.072	0.032	0.019	0.012	0.007
0.45 micron filtrate	0.104	0.052	0.024	0.015	0.010	0.006
0.22 micron filtrate	0.096	0.050	0.023	0.014	0.010	0.006
Blank	0.009	0.005				**0.005**
Standard	0.163	0.165	0.161	0.162	0.163	**0.163**

Absorbance of COD samples through 10 mm cell at 600 nm - adjusted

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.297	0.149	0.060	0.029	0.015	0.003
1.2 micron filtrate	0.137	0.067	0.027	0.014	0.007	0.002
0.45 micron filtrate	0.099	0.047	0.019	0.010	0.005	0.001
0.22 micron filtrate	0.091	0.045	0.018	0.009	0.005	0.001

APPENDIX A-4 (continued)

COD Concentration - Calculated

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	940	472	190	92	47	9
1.2 micron filtrate	434	212	85	44	22	6
0.45 micron filtrate	313	149	60	32	16	3
0.22 micron filtrate	288	142	57	28	16	3

Coagulated and filtrated test results

Alum dose (mg/l)	transmittance(%)	Absorbance	Turbidity	COD-abs	COD (mg/l)	**Transmittance after ultracentrifugation (%)**
400	5.6	1.252		0.072	212	**5.6**
800	13.3	0.876		0.058	168	**13.4**
1200	14.3	0.845		0.057	165	**14.6**
1600	21.3	0.672		0.053	152	**21.7**
2000	24.4	0.613		0.044	123	**25.2**
2400	26.3	0.580		0.039	108	**28.8**

	COD absorbance of samples from other farms		**COD concentration**	
	Raw	1600 mg/l	Raw	1600 mg/l
farm A	0.285	0.039	886	108
Farm B	0.065	0.021	190	51
Farm C	0.136	0.016	415	35
Farm D	0.303	0.035	943	95
Farm E	0.268	0.031	832	82
Farm F	0.278	0.045	864	127

Effects of 1600 mg/l alum coagulation settling time on transmittance at 254 nm

effluent source	Transmittance (%) at 2 hours *with filtration 2 hours		Transmittance at 24 hours **without filtration 24 hours
farm A	Farm A	20.8	24.8
Farm B	Farm B	37.2	45.2
Farm C	Farm C	43.1	51.7
Farm D	Farm D	25.3	27.5
Farm E	Farm E	32.1	39.4
Farm F	Farm F	22.1	29.7

!!! at 800 mg/l alum dose, sample 5607 reached 56.3% at 24 hour with no filtration

APPENDIX A-4 (continued)

BOD Results

time (days)	no4-1	no4-2	No.4	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F
0	0	0	0	0	0	0	0	0	0
1	12	12	12	10	1	1	3	3	35
3	106	107	106.5	60	3	24	70	50	102
4	113	125	119	66	4	25	78	53	108
5	130	158	144	81	5	33	102	78	126
6	138	171	154.5	96	7	40	120	90	142
7	150	184	167	107	10	45	135	100	158
9	162	214	188	127	18	54	158	112	188
12	184	211	197.5	151	20	64	178	130	215
13	192	219	205.5	160	22	66	187	134	221
14	198	247	222.5	165	22	70	192	140	225
15	201	260	230.5	170	23	71	201	141	230
16	206	254	230	173	24	73	207	144	236
18	217	254	235.5	183	26	75	218	153	242
22	232	254	243	197	28	81	235	165	250

APPENDIX A-5
EXPERIMENTAL DATA - NOVEMBER TEST

UV Disinfaction Experiment V---04/11/1997

Monitoring Results

pH: 8.10
Temperature: 16.0 C
Turbidity: 534 NTU
Electrical Conductivity: 2459microsimens/cm
Supended Solids: 356, 408 mg/l or 382 mg/l in average

COD & Transmittance/ Absorbance Test Results

Transmittance through 10 mm quartz cell at 254 nm(%)

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.0	0.0	2.7	16.1	40.2	83.2
1.2 micron filtrate	0.0	1.5	11.7	34.4	51.5	89.7
0.45 micron filtrate	0.5	7.1	34.5	58.7	75.3	94.2
0.22 micron filtrate	0.6	7.7	35.0	59.2	76.2	94.8

Absorbance through 10 mm quartz cell at 254 nm

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	7.910	3.955	1.574	0.792	0.396	0.080
1.2 micron filtrate	4.650	1.837	0.931	0.463	0.288	0.047
0.45 micron filtrate	2.290	1.146	0.462	0.231	0.123	0.026
0.22 micron filtrate	2.239	1.116	0.456	0.228	0.118	0.023

Absorbance of COD samples through 10 mm cell at 600 nm - measured

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.297	0.154	0.064	0.035	0.020	0.008
1.2 micron filtrate	0.140	0.060	0.033	0.019	0.014	0.006
0.45 micron filtrate	0.094	0.052	0.024	0.014	0.010	0.006
0.22 micron filtrate	0.082	0.046	0.022	0.013	0.009	0.006
Blank	0.009	0.005				**0.005**
Standard	0.163	0.165	0.161	0.162	0.163	**0.163**

Absorbance of COD samples through 10 mm cell at 600 nm - adjusted

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	0.292	0.149	0.059	0.030	0.015	0.003
1.2 micron filtrate	0.135	0.055	0.028	0.014	0.009	0.001
0.45 micron filtrate	0.089	0.047	0.019	0.009	0.005	0.001
0.22 micron filtrate	0.077	0.041	0.017	0.008	0.004	0.001

APPENDIX A-5 (continued)

COD Concentration - Calculated

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw pond effluent	924	472	187	95	47	9
1.2 micron filtrate	427	174	89	44	28	3
0.45 micron filtrate	282	149	60	28	16	3
0.22 micron filtrate	244	130	54	25	13	3

Coagulated and filtered test results

Alum dose (mg/l)	transmittance(%)	Absorbance	Turbidity	COD-abs	COD (mg/l)
400	6	1.222		0.068	199
800	12	0.921		0.058	168
1200	17.1	0.767		0.057	165
1600	21.6	0.666		0.055	158
2000	26	0.585		0.044	123
2400	26.7	0.573		0.041	114

Effect of settling time and stirring duration (%transmittance)

settling time (min.)	1 min.	2 min.	5 min.	30 min.	1440 min.	1 min.	2 min.	5 min.	30 min.	1440 min.
30	13.7	13.5	14.3	5.6	0.0	21.6	20.8	20.8	20.6	7.3
120	14.7	13.7	14.6	8.1	0.2	21.8	20.9	21.7	21.1	11.5
360	14.7	14.7	14.7	7.2	0.2	21.2	19.4	20.9	19.2	11.6
1440	17.7	18.3	14.7	8.2	0.3	21.4	20.5	21.4	20.6	12.5
2880	17.8	17.9	15.1	9.8	0.4	21.2	21.6	20.9	20.4	12.5
7200	18.1	18.3	16.0	11.3	1.3	22	22.1	21.3	20.6	13.9

* No4 sample coagulated with 1600 mg/l alum **after filtration

Effect of AC adsorption (% transmittance)

time (hour)/ dose (g/l)	0	0.2	0.5	5
24 hours	20.5	47.8	75.7	88.3
24 hours	20.4		79.9	88.4
48 hours	20.5	56.8	86.3	88.4
120 hours	20.5	61.8	86.4	88.4

Effect of Hydrogen Peroxide (%transmittance)

time (hour)/ dose (g/l)	0	1	5
24 hours	20.5	11.4	2.8
48 hours	20.5	17.2	13.5
96 hours	20.5	19.3	18.5
168 hours	20.5	20.1	18.5

* 5% hydrogen peroxide dilution gave 5.6% transmittance.

APPENDIX A-6
EXPERIMENTAL DATA - DECEMBER TEST

UV Disinfection Experiment VII---9 am 18/12/1997

Monitoring Results

Temperature: 18.3 C
Turbidity: 506 NTU
EC: 2350
Suspended Solids (total):494 mg/l. 484 mg/l, or 489 mg/l in average.

COD & Transmittance Test Results

Transmittance through 10 mm quartz cell at 254 nm (%)

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw FDWW	0.0	0.0	2.2	15.0	38.2	82.6
1.2 micron filtrate	0.0	0.7	14.1	37.6	61.8	90.6
0.45 micron filtrate	0.3	5.4	31.2	55.6	75.0	94.2
0.22 micron filtrate	0.6	8.4	36.6	60.6	78.9	95.1

Absorbance through 10 mm quartz cell at 254 nm

Dilution	1	0.5	0.2	0.1	0.05	0.01
Raw FDWW	8.23	4.151	1.649	0.823	0.417	0.083
1.2 micron filtrate	4.298	2.149	0.852	0.425	0.209	0.043
0.45 micron filtrate	2.587	1.264	0.506	0.254	0.125	0.026
0.22 micron filtrate	2.235	1.077	0.437	0.218	0.108	0.022

COD Results

	Abs at 600 nm	COD (mg/l)
Raw FDWW	0.304	933
1.2 micron filtrate	0.152	466
0.45 micron filtrate	0.102	313
0.22 micron filtrate	0.088	270
400 mg/l-alum	0.06	184
800 mg/l-alum	0.051	156
1200 mg/l-alum	0.046	141
1600 mg/l-alum	0.045	138
2000 mg/l-alum	0.036	110
2400 mg/l-alum	0.044	135

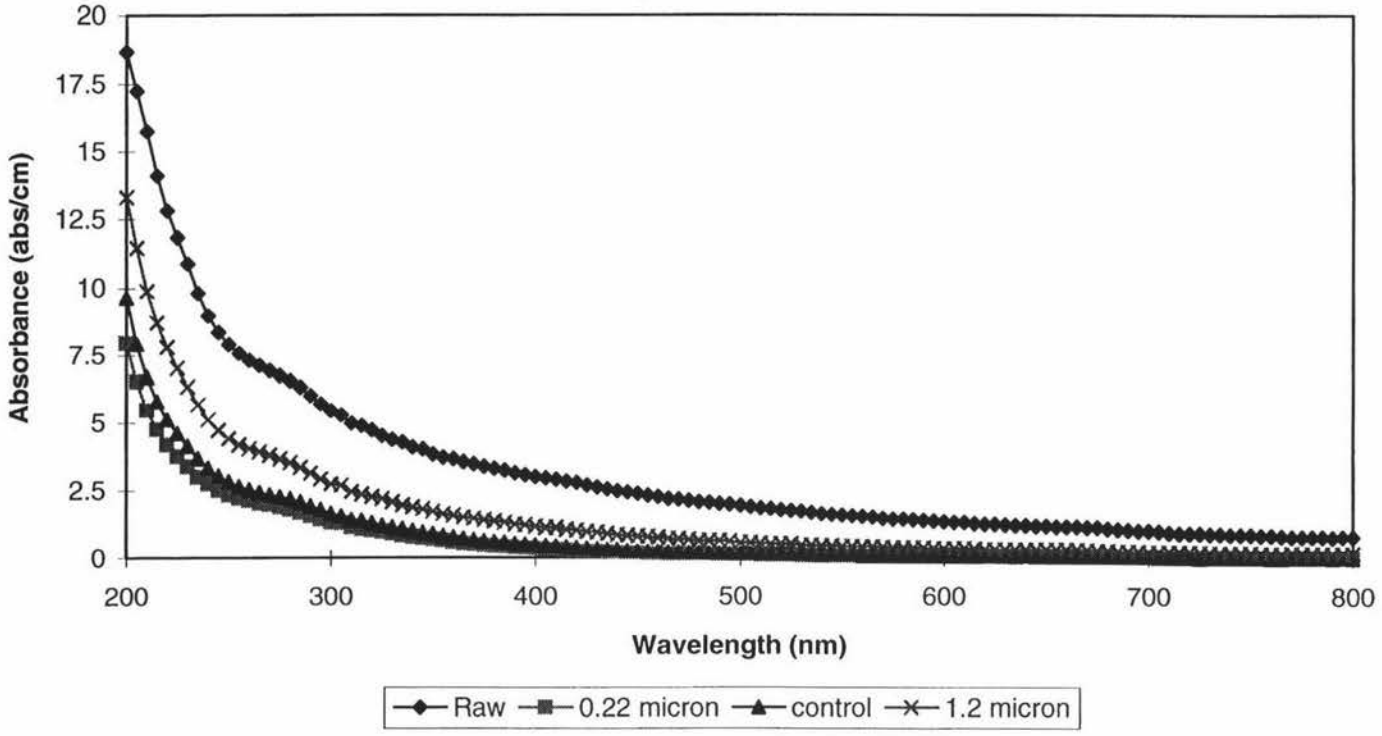
APPENDIX A-6 (continued)

	Absorbance at 254 nm	Transmittance at 254 nm
0.1g/lac-.45	0.407	39.2
0.2g/lac-0.45	0.276	53.0
0.5g/lac-0.45	0.102	79.1
1g/lac-0.45	0.048	89.5
2g/lac-0.45	0.017	96.2
3g/lac-0.45	0.01	97.7
0.22 micron	2.24	0.6
0.45 micron	2.68	0.2
1.2 micron	4.21	0.0
raw	7.63	0.0
2400-alum-0.45	0.506	31.2
2000-alum-0.45	0.578	26.4
1600-alum-0.45	0.692	20.3
1200-alum-0.45	0.874	13.4
800-alum-0.45	1.191	6.4
10g/lzeolite-0.45	0.717	19.2
10g/lzeolite-raw	1.265	5.4
50g/lbarkA-0.45	1.305	5.0
50g/lbarkB-0.45	1.583	2.6
50g/lbarkA-Raw	2.145	0.7
50g/lbarkB-Raw	2.488	0.3
1600mg/l-0.45	0.652	22.3
0.5g/lac-Raw	1.391	4.1
1g/lac-Raw	0.832	14.7
2g/lac-Raw	0.348	44.9
5g/lac-Raw	0.222	60.0
10g/lac-Raw	0.108	78.0

BOD Test Results (average of duplicates)

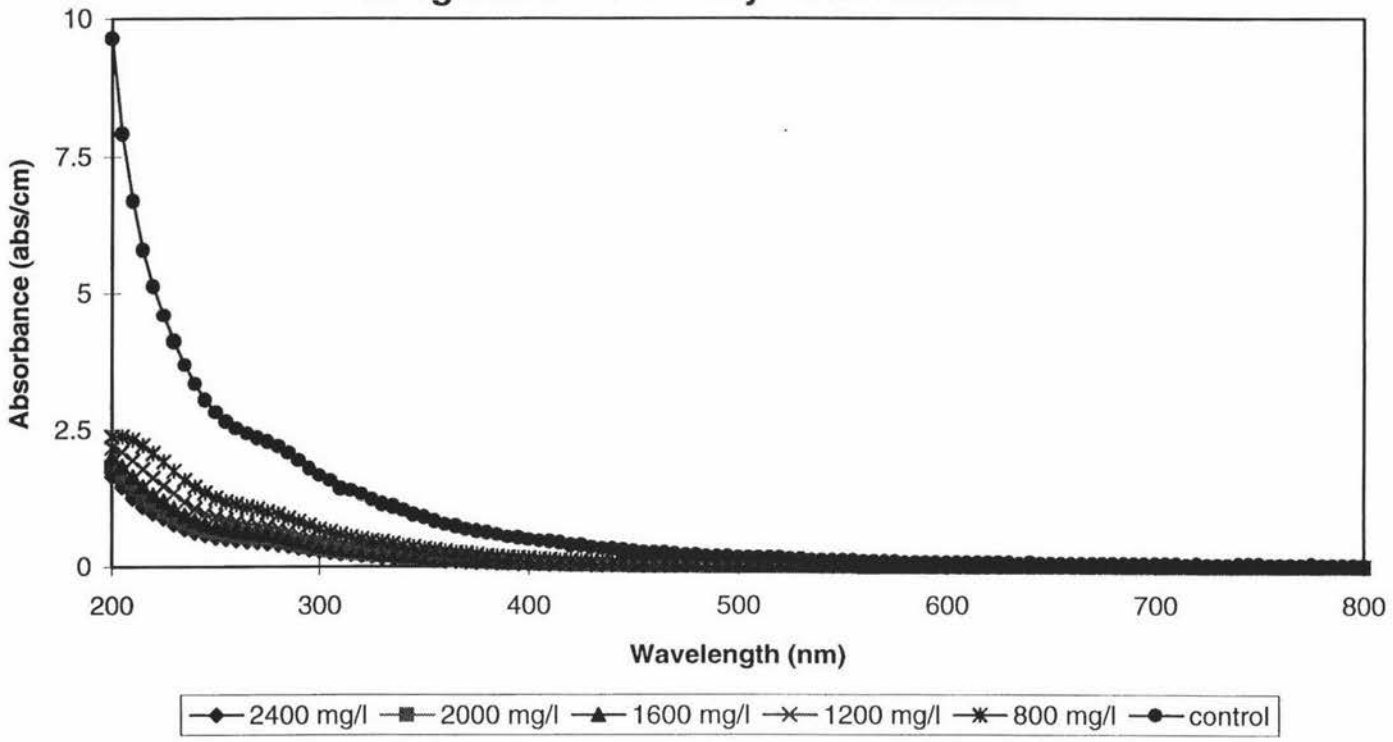
time (days)	Raw	0.45
0		
1	31	28
2	82	30
3	114	33
4	136	35
5	158	40
6	172	41
11	214	50
18	246	60

APPENDIX B-1 Absorbance Spectra of Raw and Filtrated Farm Dairy Pond Effluent



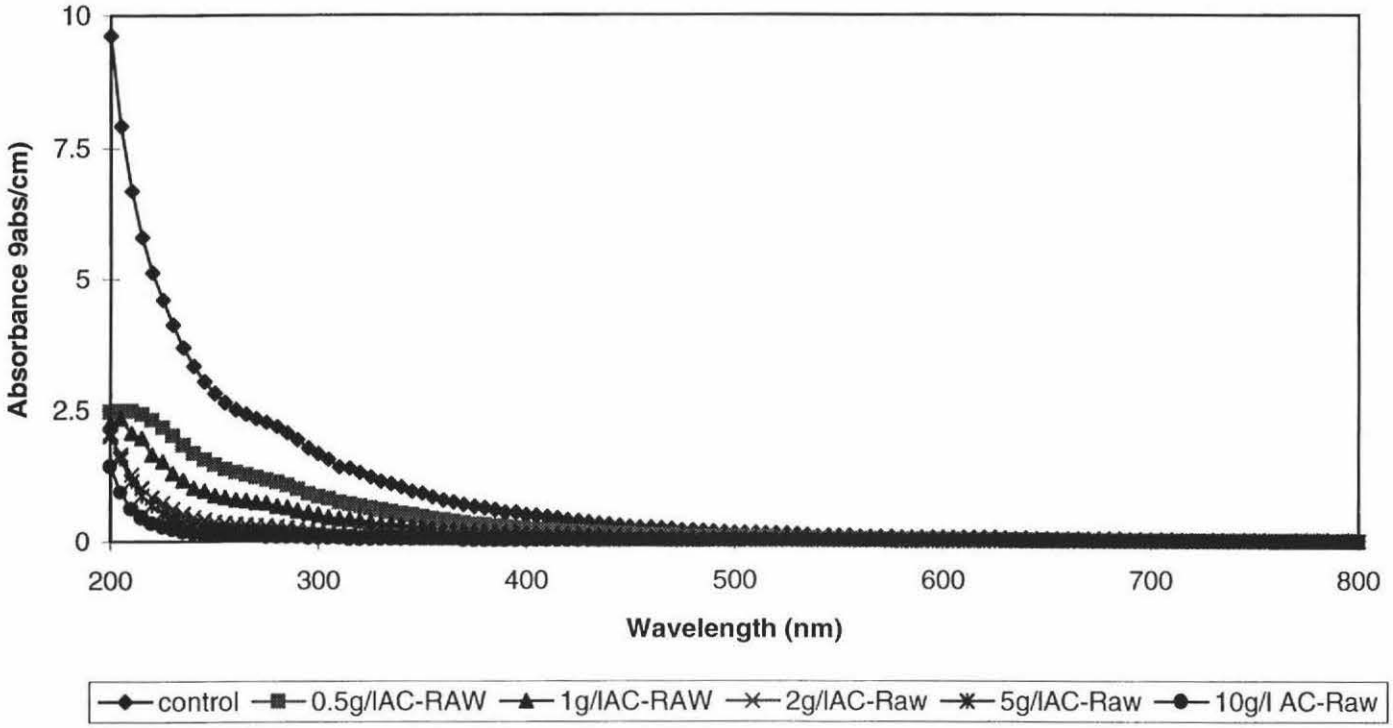
* raw = raw farm dairy pond effluent (Massey No. 4).

APPENDIX B-2 Absorbance Spectra of Raw and Alum Coagulated Farm Dairy Pond Effluent



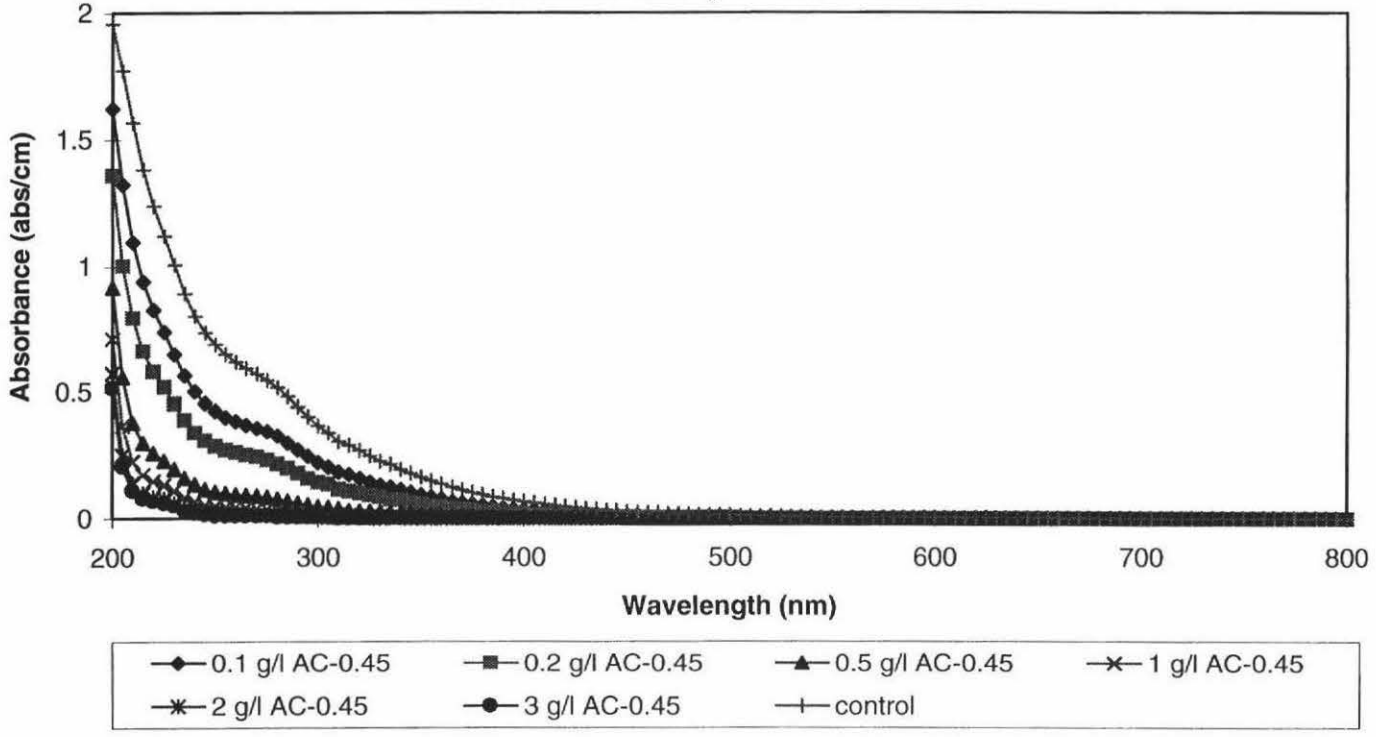
*control = 0.45 micron filtrate of farm dairy pond effluent (Massey No. 4).

APPENDIX B-3 Absorbance Spectra of Activated Carbaon (AC) Treated Raw Pond Effluent



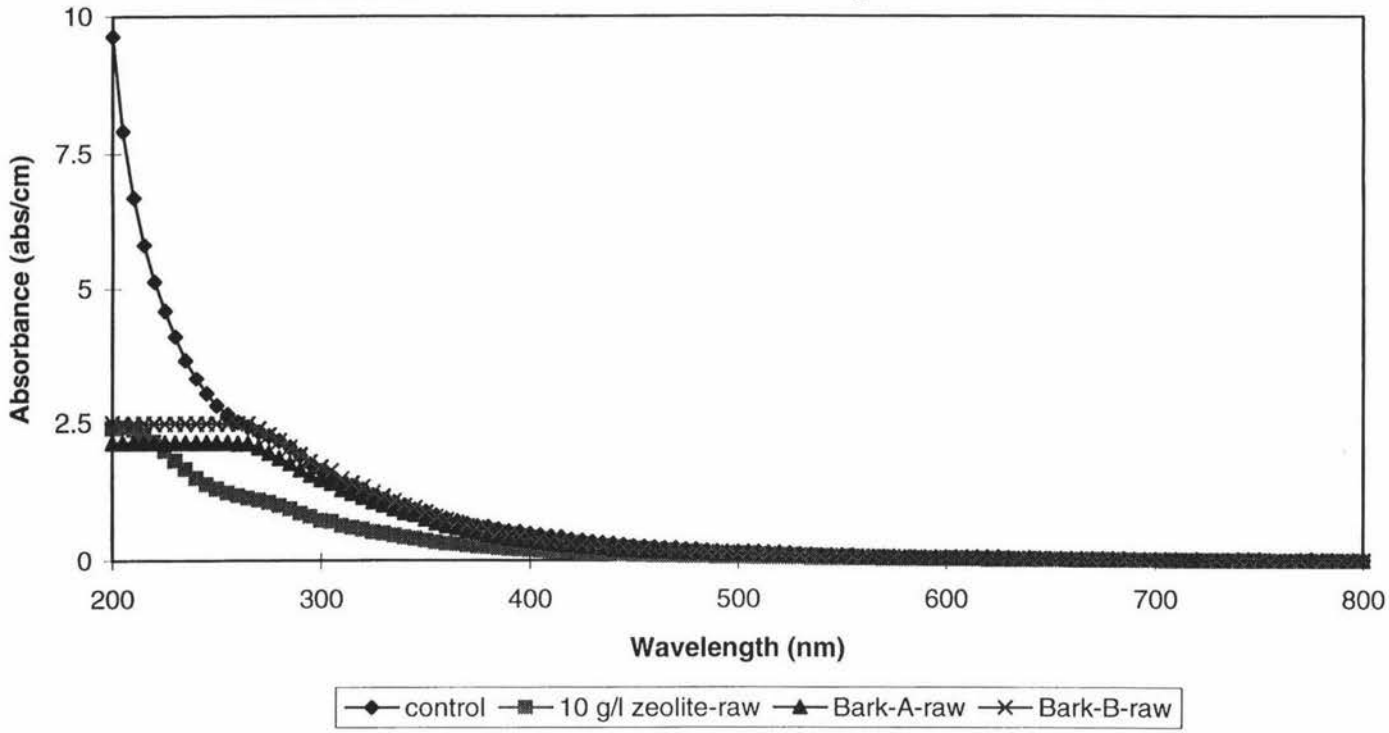
*control = 0.45 micron filtrate of farm dairy pond effluent (Massey No. 4).

APPENDIX B-4 Absorbance Spectra of Activated carbon (AC) Treated Farm Dairy Pond Effluent



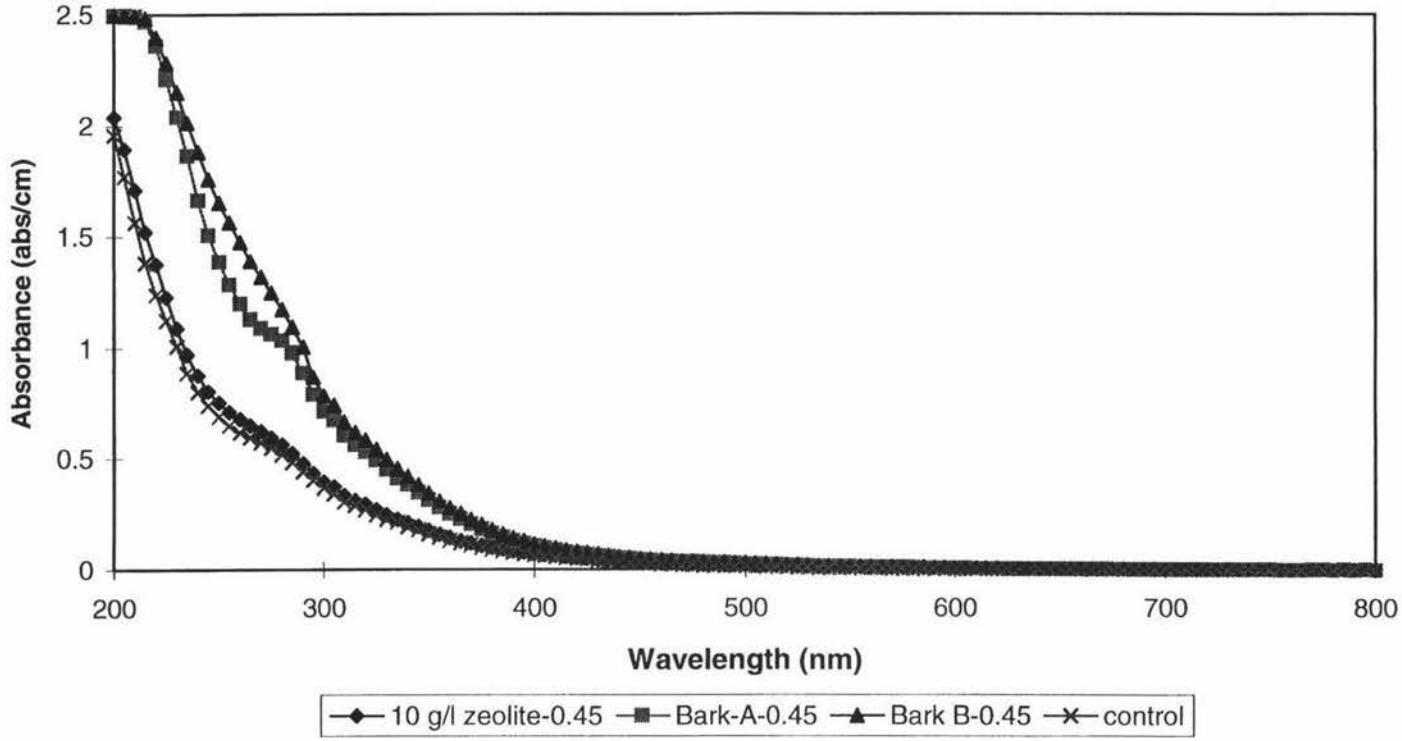
*control = 0.45 micron filtrate after 1600 mg/l alum coagulation of farm dairy pond effluent (Massey No. 4).

APPENDIX B-5 Absorbance Spectra of Bark and Zeolite Treated and Non-treated Farm Dairy Pond Effluent



*control = 0.45 micron filtrate of raw farm dairy pond effluent (Massey No. 4).

APPENDIX B- 6 Absorbance Spectra of bark, Zeolite Treated and Non-treated Farm Dairy Pond Effluent after Alum Coagulation



*control = 0.45 micron filtrate after 1600 mg/l alum coagulation of farm dairy pond effluent (Massey No. 4).