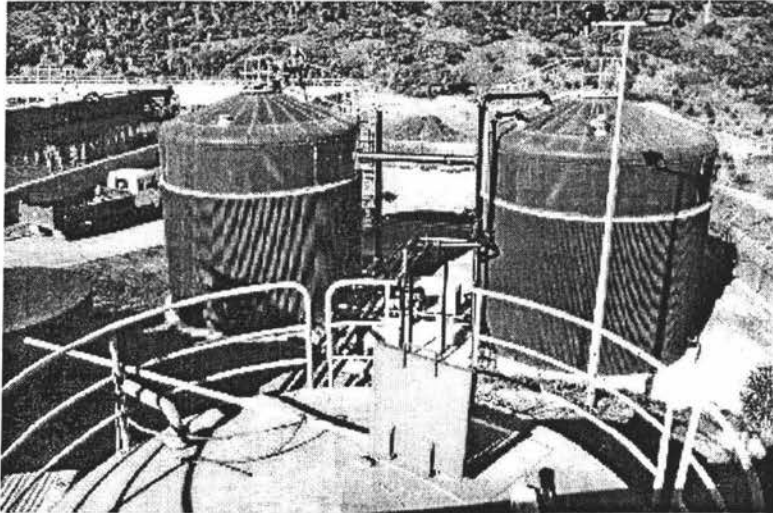


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**MODEL BASED STUDY OF AUTOTHERMAL
THERMOPHILIC AEROBIC DIGESTION (ATAD)
PROCESSES**



**A thesis presented in partial fulfilment of the requirements for the Degree of
Master of Technology in Engineering and Automation of Massey University.**

BARRY FRYER

2000

Summary

An Autothermal Thermophilic Aerobic Digestion (ATAD) process is a relatively new sewage sludge treatment process. The ATAD process is capable of stabilising and pasteurising sewage sludge so that it can be applied to land as a soil additive or fertiliser with minimal environmental and public health risks. A mathematical model was successfully developed to describe the dynamic behaviour of ATAD processes, which was used extensively to investigate possible improvements to the design, operation and control of ATAD processes.

Every aeration system has an oxygen transfer efficiency that maximises the net heat production of the entire system. The aeration system can be controlled to this optimal oxygen transfer efficiency with a simple PI controller. This control strategy also ensures that sufficient oxygen is supplied to the microorganisms. Therefore increasing the rate of stabilisation and disinfection, and hence increasing throughput. Simulations have shown that the control strategy will increase performance and stability of the process, and consequently reduce capital and operational costs.

Simulations showed that the draw and fill strategy has a strong influence on the performance of the system. Unfortunately there are no clear-cut answers to optimising this, as it is very system dependent. The largest sludge throughput is achieved when the disinfection and the stabilisation criteria are achieved at similar times, without saturating the aeration system or dropping the reactor temperature below 50°C. If the disinfection criterion is the system's constraint for prolonged periods the bacteria population can diminish due to lack of available organic substrates, which can result in process instability.

The mathematical model was used as the basis of a prototype ATAD Design and Simulation software package. This will allow designers to explore different operational and design scenarios before the design even reaches the drawing table.

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I would like to thank the team at Waste Solutions Ltd. for their continued support and encouragement throughout this project, especially my supervisors Dr. Tico Cohen and Nathan Clarke.

I would like to thank Nelson City Council and NelMac for allowing me to observe the operation of the ATAD systems at Nelson's Bells Island Sewage Treatment Plant. This provided valuable insight into an actual ATAD system.

Nomenclature

State Variables

SBS(t)	Concentration of slowly biodegradable substrate, (mg/l)
RBS(t)	Concentration of readily biodegradable substrate, (mg/l)
NBS(t)	Concentration of non biodegradable substrate, (mg/l)
VFA(t)	Concentration of Volatile Fatty Acids, (mg/l)
$X_M(t)$	Concentration of mesophilic bacteria, (mg/l)
$X_T(t)$	Concentration of thermophilic bacteria, (mg/l)
DO(t)	Concentration of dissolved oxygen, (mg/l)
Ht(t)	Height of liquid in reactor, (m)
T(t)	Reactor temperature, ($^{\circ}\text{C}$)

Output Variables

T(t)	Reactor temperature, ($^{\circ}\text{C}$)
VS(t)	Volatile solids concentration, (mg/l)

Input Variables

$Q_{\text{air}}(t)$	Air flow rate, (m^3/s)
$P_{\text{Blow}}(t)$	Power consumed by blower, (W)
$P_{\text{pump}}(t)$	Power consumed by re-circulation pump, (W)
$T_{\text{air}}(t)$	Temperature of ambient air, ($^{\circ}\text{C}$)
$T_{\text{in}}(t)$	Temperature of the feed sludge stream, ($^{\circ}\text{C}$)
$\dot{M}_{\text{in}}(t)$	Mass flow of sludge into reactor, (kg/s)
$\dot{M}_{\text{out}}(t)$	Mass flow of sludge out of reactor, (kg/s)

Other Variables

General Variables

H_{gas}	Humidity of exhaust gas stream, (kg of water/kg of air)
H_{amb}	Humidity of the inlet ambient air, (kg of water/kg of air)
V	Process water volume, (m^3)
A	Cross sectional area of reactor, (m^2)

VS	Volatile Solids concentration, (kg of VS/kg of wastewater)
VS _{Reduction}	Fraction of Volatile Solids reduced during ATAD process
Q	Daily sludge loading, (m ³ /day)
VSL	Volatile Solids Loading, (kg of VS/day)
OTE _{Design}	Design Oxygen Transfer Efficiency, (%)
ρ_{air}	Density of air gas stream, (kg/m ³)
ρ	Density of sludge, (kg/m ³)
M _{react}	Mass of sludge in reactor, (kg)
M _{evap} [•]	Rate of water evaporated from reactor, (kg/sec)

Heat Variables

U	Overall heat transfer coefficient, (W/m ² °C)
C _p	Specific Heat Capacity of the sludge, (J/kg °C)
C _{pair}	Specific Heat Capacity of air stream, (J/kg °C)
λ	Thermal conductivity, (W/K m)
h	Film heat transfer coefficient, (W/m ² °C)
h _{react}	Heat produced per kg of oxygen consumed (J/kg of O ₂ consumed)
h _{evap}	Latent heat of vaporisation, (J/kg)
η_{Blow}	Efficiency of blower
η_{pump}	Efficiency of re-circulation pump
ϕ_{wall}	Heat lost through reactor walls, (W)
ϕ_{sludge}	Sensible heat lost by sludge flows, (W)
ϕ_{Air}	Sensible heat lost by air flow through the reactor, (W)
ϕ_{evap}	Heat lost by evaporation of water from reactor, (W)
ϕ_{react}	Heat produced by biochemical reaction, (W)
ϕ_{mech}	Heat produced by mechanical devices, (W)
ϕ_{aeration}	Net heat produced as a result of the air supply, (W)

Aeration/ Oxygen Variables

OTR(t)	Oxygen transfer rate, (mg/s)
OUR(t)	Oxygen usage rage, (mg/s)
OTE(t)	Oxygen transfer efficiency, (%)
αF	Process water K _L a / clean water K _L a

K_{La20}	Apparent volumetric oxygen mass transfer coefficient in water, (hr^{-1})
θ	Temperature adjustment coefficient
τ	Temperature correction factor for dissolved oxygen saturation
Ω	Pressure correction factor for dissolved oxygen saturation
β	Saturation modifier (process water/clean water)
C_s	Dissolved oxygen surface saturation concentration at water temperature, T, standard atmospheric pressure and 100% relative humidity, (mg/l)
C_{s20}	Dissolved oxygen saturation concentration at 20°C and standard atmospheric pressure, (mg/l)
$C_{\infty 20}$	Steady state dissolved oxygen saturation concentration at infinite time and standard conditions, (mg/l)
P_B	Field atmospheric pressure, (kPa)
P_{vT}	Vapour pressure of water at temperature T, (kPa)
P_s	Atmospheric pressure at standard conditions, (kPa)
d_E	Effective saturation depth, (m)
A_{air}	Aeration system performance coefficient
B_{air}	Aeration system performance coefficient
U_{SG}	Superficial gas velocity, ($\text{m}^3/\text{m}^2/\text{day}$)
$Q_{air Opt}$	Optimal airflow rate, (m^3/sec)

Biochemical Reaction Variables

X	General bacteria concentration, (mg/l)
S	General bacterial substrate, (mg/l)
K_s	General substrate limitation, (mg/l)
μ	Specific bacterial growth rate constant, (1/sec)
μ_m	Maximum specific bacterial growth rate constant, (1/sec)
k_m	Specific rate constant for mesophilic bacteria, (1/sec)
k_t	Specific rate constant for thermophilic bacteria, (1/sec)
Y	Yield coefficients, (mg/mg)
Y_{Oxy}	Yield coefficient for dissolved oxygen, (mg/mg)
K_{SBS}	Rate limit for slowly biodegradable substrate, (mg/l)
K_{RBS}	Rate limit for readily biodegradable substrate, (mg/l)

K_{VFA}	Rate limit for Volatile Fatty Acids, (mg/l)
K_{DO}	Rate limit for dissolved oxygen in the oxidation pathway, (mg/l)
K_{DOf}	Rate limit for dissolved oxygen in the fermentation pathway, (mg/l)

Subscripts

Reaction	Accumulation of substrate due to the biochemical reaction
1	Biochemical pathway from SBS to RBS, (hydrolysis)
2	Biochemical pathway from RBS to bacteria, (oxidation)
3	Biochemical pathway from RBS to VFA, (fermentation)
4	Biochemical pathway from VFA to bacteria, (oxidation)
5	Biochemical pathway from bacteria to RBS, (lysis)
6	Biochemical pathway from bacteria to SBS, (lysis)
7	Biochemical pathway from bacteria to NBS, (lysis)

Common Abbreviations

ADP	Adenosine Diphosphate
ATAD	Autothermal Thermophilic Aerobic Digestion
ATP	Adenosine Triphosphate
EPA	Environmental Protection Agency
FAD	Flavin Adenine Dinucleotide
FADH	Flavin Adenine Dinucleotide Hydroxide
FSD	Full Scale Deflection
HRT	Hydraulic Residence Time
NAD	Nicotinamide Adenine Dinucleotide
NADH	Nicotinamide Adenine Dinucleotide Hydroxide
NBS	Non Biodegradable Substrate
OTE	Oxygen Transfer Efficiency
OTR	Oxygen Transfer Rate
OUR	Oxygen Usage Rate
PI	Proportional-Integral Controller
PID	Proportional-Integral-Derivative Controller
RBS	Readily Biodegradable Substrate
SBS	Slowly Biodegradable Substrate

SOUR	Specific Oxygen Usage Rate (determined at standard conditions)
TCA	Tricarboxylic Acid
TS	Total Solids
USEPA	United States Environmental Protection Agency
VFA	Volatile Fatty Acids
VS	Volatile Solids

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1. Introduction

An Autothermal Thermophilic Aerobic Digestion process, or ATAD process, is a relatively new sewage sludge treatment process. The ATAD process has been developed for the disinfection and stabilisation of sewage sludge, which is a by-product of wastewater treatment. The end product can be applied to the land as a soil additive or fertiliser with no restrictions, as the process dramatically reduces public health and environmental risks. The process is comparable to the composting process used for municipal solid waste and garden wastes.

The process requires oxygen, usually in the form of air, to be applied to the sludge by an aeration system. The oxygen stimulates an exothermic biochemical reaction, which in turn heats the sludge up to thermophilic temperatures (between 50 and 65°C). At these temperatures the pathogenic bacteria, viruses and parasites in the sludge that are harmful to human health are effectively destroyed. The biochemical reaction also degrades a large portion of the organic sludge, which means that unstable, volatile odour generating substances are removed; this reduces the likelihood of smells and the attraction of flies and rodents (vector attraction) to the sludge.

ATAD processes have been widely and successfully implemented in a number of countries around the world, in particular Canada and Europe (Kelly, *et al*, 1993). In New Zealand the ATAD process has only been in operation for about 3½ years and during this time a number of difficulties have been encountered. This thesis was undertaken in an effort to better identify areas of potential difficulties and to reduce the capital and operational costs of an ATAD process.

The main objective of the project was to provide a deeper understanding into the design, operation and control of an ATAD process so that designers and consultants at Waste Solutions Ltd are capable of making informed decisions. A dynamic non-linear mathematical model was developed that includes mass and energy balances along with rudimentary biochemical degradation equations.

The potential uses of this ATAD model are virtually unlimited, but the key areas of interest in this thesis are the effects of air supply rates, draw and fill cycles and Volatile Solids concentrations on the overall performance of an ATAD system. The model has also been used to investigate an ATAD's physical design and the need for temperature and aeration control.

The thesis describes the physical and biochemical ATAD process in detail in Sections 2 and 4 respectively, with a brief biochemical background in Section 3. The mathematical model is developed in Section 5 and validated in Section 6. Section 7 discusses the issues associated with ATAD design; this includes the characteristics of the reactor and the aeration system, the effects of sludge concentrations, and the benefits of multistage ATAD systems. The operational issues investigated are discussed in Section 8, these include possible control strategies, draw and fill strategies, and possible ways of dealing with variations in sludge loads. Section 9 discusses the control an ATAD system with the proposed oxygen transfer efficiency – aeration rate control strategy.

2. Process Description

An Autothermal Thermophilic Aerobic Digester (ATAD) is a process that treats sewage sludge, a by-product of wastewater treatment. The ATAD process is capable of stabilising and disinfecting both primary and secondary sewage sludge to the United States Environmental Protection Agency (USEPA) Class A biosolid standard (assuming the feed sludge contains sufficiently low levels of heavy metals). The end product of the ATAD process can therefore be beneficially applied to land as a soil additive or fertiliser with no restrictions, as the process dramatically reduces public health and environmental risks.

Primary sewage sludge is the solids that result from the primary screenings of the raw sewage that enters a sewage treatment plant. Secondary sewage sludge, sometimes called waste activated sludge (WAS) is the solids that are recovered from a sewage treatment process such as an aeration basin, sequential batch reactor (SBR), trickling filter, etc. Both of these sludge sources can have considerably different degradation rates and calorific values.

With an adequate supply of oxygen, microorganisms, nutrients and biodegradable organic material an ATAD can degrade complex organic substrates into stable end products, which include carbon dioxide and water. Some of the energy released by microbial degradation is used to form new cellular material but much of it is released as heat. When this heat is retained it pasteurises the sludge.

An ATAD process consists of an enclosed insulated reactor in which concentrated sewage sludge (or biosolids) is both mixed and aerated, as shown in Figure 1. The process requires oxygen, usually in the form of air, to be applied to the sludge by an aeration system. The oxygen stimulates an exothermic (heat releasing) biochemical reaction, which heats the sludge up to thermophilic temperatures (50-65⁰C). At these temperatures the pathogenic bacteria, viruses and parasites harmful to human health are effectively destroyed. The biochemical reaction also stabilises the sludge, which

means that unstable, volatile and odour generating substances are removed; this reduces the likelihood of malodour and vector attraction of the sludge.

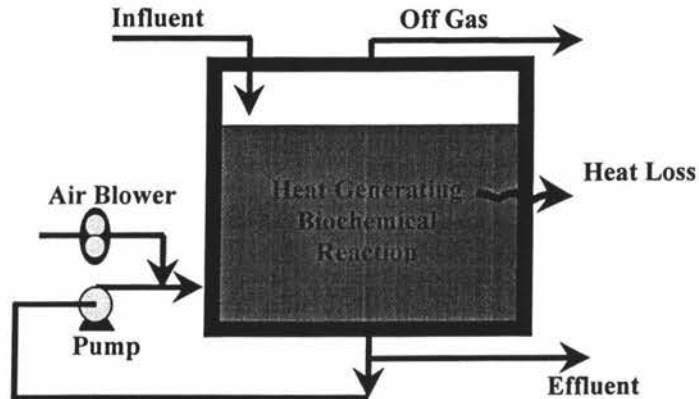


Figure 1 - Basic ATAD System

The thermophilic bacteria that are vital to the process are up to 2-8 times more active than their mesophilic (operate at 25-45⁰C) counterparts, as a result ATAD reactors are significantly smaller than other mesophilic digestion systems.

Both energy production and energy conservation are important considerations in an ATAD system to ensure that sufficient sludge disinfection can occur. As indicated from Figure 1 the key energy source is the heat releasing biochemical reaction, but the inefficiencies of the blower and the re-circulation pump also add a small amount of heat to the sludge (between 5 and 10%). Energy is lost from an ATAD system by the different temperatures of the incoming and outgoing sludge and air streams (loss of sensible heat), along with heat flow through the walls of the reactor. Energy is also lost due to the latent heat of vaporisation. The exhaust gas has a high enthalpy due to its high relative humidity.

The main advantages of an ATAD system over other sludge treatment processes is that it can produce a product that has no disposal restrictions, with relatively low energy requirements and hydraulic residence time. Since an ATAD is an aerobic process it does not produce any explosive off gases, such as methane, which requires special handling.

2.1 Main ATAD Components

An ATAD system consists of buffer tanks, insulated reactors, a foam control device, aeration equipment, mixing equipment (usually combined with aeration system), a sludge thickening device and an odour control system. Some ATAD systems also use some form of heat exchanger.

2.1.1 Buffer Tanks

Buffer tanks are usually placed before and/or after an ATAD process to equalise load variations in the system. It is quite common for an ATAD process to be before or after a continuous process and since an ATAD is normally a batch or semi-continuous process a buffer tank is required to interface the two systems.

2.1.2 Insulated Reactor

An enclosed insulated tank is used to minimise the heat loss from the processing sludge under all weather conditions. The shape and dimensions of an ATAD reactor are important for mixing and aeration efficiencies. A large number of the original ATADs built in America and Europe did not have an enclosed lid. The enclosed reactor has been found to be beneficial as it reduces heat loss and provides a means of odour control.

2.1.3 Foam Control

Uncontrolled foam production can result in biosolid spillage or over pressurising the reactor. Foam problems can be minimised by one or more of the following methods: use reduced air supply, make the foam denser through mechanical breakers, and/or provide a large head space allowance during design (Kelly and Warren, 1995). Some foaming is a necessary consequence of good oxygen transfer efficiencies (Wolinski, 1985), but excessive foaming causes problems.

2.1.4 Aeration / Mixing Devices

There are various aeration technologies used around the world in ATADs, each have their advantages and disadvantages. The two basic types of aeration technologies used in ATAD process are venturi guns and submerged turbine aspiration systems.

The venturi guns operate by circulating sludge, with a pump, from the bottom of the reactor through a venturi nozzle and back into the reactor which creates mixing. The pressure at which the sludge is pumped through the venturi nozzle causes turbulence, which allows dispersion with the air or oxygen that is injected at this point (Wolinski, 1985). The main benefits of such an aeration system are that the pump and venturi are located outside the reactor for easier repair and maintenance, and allows flexible operation as far as sludge depths are concerned. This is the method of aeration currently adopted by Waste Solutions Ltd., and therefore this investigation mainly focuses on this type of aeration system.

Submerged turbine naturally aspirated aerator/mixers utilise a motor mounted at the top of the reactor, which is driving an impeller that is submerged in sludge. The rotating impeller forms a slight vacuum in the sludge allowing air to be mixed and dispersed within the sludge, the air is delivered to the impellers through the hollow drive shaft. The disadvantages of this type of system is that it is inflexible as far as sludge operational height is concerned, insufficient oxygen transfer can result if foam is not effectively controlled (due to the impeller operating in foam not sludge) and the physical arrangement of the system can make repair and maintenance difficult.

Pure oxygen was initially the predominate source of oxygen for ATAD reactors as it was thought that the air would cause too much cooling to allow thermophilic temperatures to be reached. In the late 1970s and early 1980s it became apparent that it was possible to aerate an ATAD with air and therefore significant savings in operational costs were made.

2.1.5 Sludge Thickeners

For an ATAD process to generate sufficient heat to maintain thermophilic temperatures some form of pre-sludge thickening process is usually required to allow the sludge concentration to get into an acceptable range. The general 'rule of thumb' used is that a sludge concentration should be between 3 and 8% on a dry basis. A full discussion on this 'rule of thumb' is included in Section 7.3.1.

Often Total Solids (TS) and Volatile Solids (VS) are confused. Total Solids concentration is the mass of dry solids in the sludge divided by the total mass of sludge. The Volatile Solids concentration is the mass of dry solids in the sludge that can be oxidised divided by the total mass of sludge. Generally the solids in the sludge consist of between 70 and 90% Volatile Solids and the remainder is ash. It is the quantity of Volatile Solids that is of importance in an ATAD process as this represents the amount of organic material that can be degraded. Generally not all the Volatile Solids are degraded in an ATAD process.

Post ATAD sludge thickeners are also often used to reduce the quantity of sludge to be disposed of. This is largely dependent on how and where the sludge is being disposed of, and therefore some ATAD facilities do not require post ATAD sludge thickeners.

The type of sludge thickeners used for ATAD systems depends largely on the scale of the operation. Gravity thickeners, rotary drum thickeners, centrifuges, belt presses, dissolved air flotation thickeners are just a few that have been successfully used.

2.1.6 Odour Control

An odour control system is often used to minimise the affects of malodour from an ATAD system. It is a common belief that a well aerated ATAD process does not produce malodour, however it is still common for the exhaust gas of an ATAD system to have some type of treatment before it is released into the atmosphere. Edgington and Clay (1992) reported that an ATADs odour was not a problem, but was identified to be unpleasant during start up.

Some effective odour control systems include wet scrubber systems, biofilters or simply diversion of the exhaust gas to other sewage treatment processes.

2.1.7 Heat Exchangers

In principle heat exchangers are not required to operate an effective ATAD process, but they can be used in various configurations for different reasons. The underlining reasons for adding heat exchangers to an ATAD are either economic or process

specific. The benefits and requirements of heat exchangers are discussed in more detail in Section 8.6.

2.2 Process Requirements

The sewage sludge that is extracted from primary screenings and/or wastewater treatment processes is becoming more difficult to dispose of with today's increasing environmental regulations. An ATAD process has the capability of transforming the sludge into a stable and pasteurised product that has minimal environmental and health risks. Therefore the biosolids can be used beneficially as a soil additive or fertiliser.

An ATAD process is capable of processing sludge to the United States Environmental Protection Agency's (USEPA) Class A biosolids standard, which allows sludge to be disposed of (or used) with no restrictions. The two key criteria are stabilisation and disinfection, to achieve these criteria an ATAD system must operate in either a batch or semi-continuous mode, as discussed in Section 2.2.3.

2.2.1 Stabilisation

Raw sewage sludge contains unstable, volatile and odour generating substances that causes malodour and attracts pests such as flies, rats and mice. If the sludge is to be applied to land as a soil additive or fertiliser then this vector attraction must be minimised.

The United States Environmental Protection Agency (USEPA) regulates the application of sludge to land. The USEPA through 40CFR Section 503.33 states that biosolids must meet 1 of the 8 vector attraction criteria listed before it can be applied to land with no restrictions. The two criteria that can be best applied to an ATAD process are listed below:

- 1) At least 38% Volatile Solid reduction must be achieved
- 2) The specific oxygen uptake rate for sewage sludge treated in an aerobic process shall be equal to or less than 1.5 milligrams of oxygen per hour per gram of Total Solids at a temperature of 20⁰C.

(Environmental Protection Agency, 1995)

2.2.2 Disinfection

If biosolids are to be disposed of on land it is very important that all the pathogenic bacteria, virus and parasites which are harmful to human health are destroyed. The pathogens that are of major concern in sewage sludge are fecal coliforms, salmonella sp., enteric viruses and helminth ova. Such pathogens are typically mesophilic and therefore do not survive at temperatures above 47°C for prolonged periods. An ATAD process operates at temperatures higher than 55°C and therefore is a feasible method for controlling pathogens (Pagilla, *et al*, 1996).

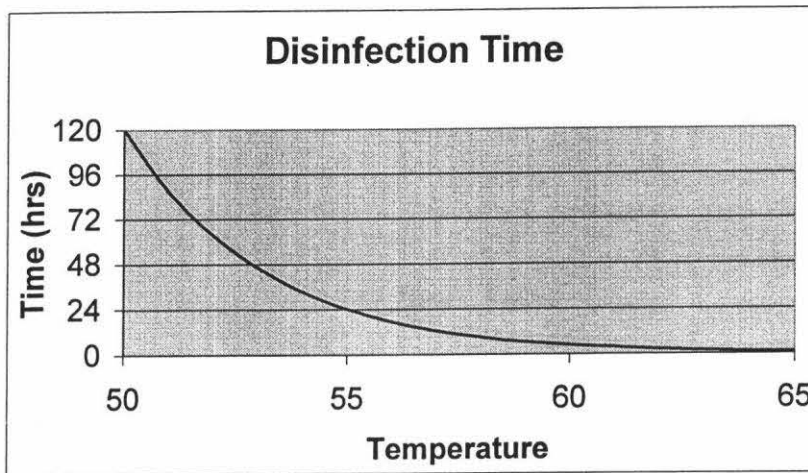


Figure 2 - The relationship between temperature and the time required for sludge disinfection to Class A standards.

$$D = \frac{50,070,000}{10^{0.1400T}} \quad (\text{days}) \quad (1)$$

The USEPA regulates the application of biosolids to land and states in 40CFR Section 503.32 that the sewage sludge must be maintained at a specific temperature for a period of time as shown in Figure 2. For example, if the sludge was at 55°C, and this temperature (at least) is maintained for 24 hours with no additional sludge added during that period, then the sludge will meet the disinfection criterion for Class A biosolids. The equation for this line is shown in Equation 1, where T represents the sludge temperature and D represents the time it takes to sufficiently pasteurise the

sludge at the given temperature. This equation is valid for temperatures higher than 50°C and sludge concentrations less than seven percent Total Solids. 40CFR Section 503.32 outlines all the disinfection requirements, but Equation 1 represents the most common situation.

2.2.3 Draw-Fill Cycle

In order for the biosolids to meet the required disinfection requirements an ATAD process must operate in either a complete batch or semi-continuous mode. A continuous process would allow some sludge to short circuit the reactor and hence insufficient disinfection would not occur.

A batch or semi-continuous operation causes sudden dramatic energy loads on the system as a result of the cold raw sludge that is added in each cycle. The temperature profile of an ATAD system is therefore a saw tooth type profile similar to that shown in Figure 3. The temperature rarely reaches a steady state condition during a cycle, therefore the operation and control of an ATAD process is very challenging.

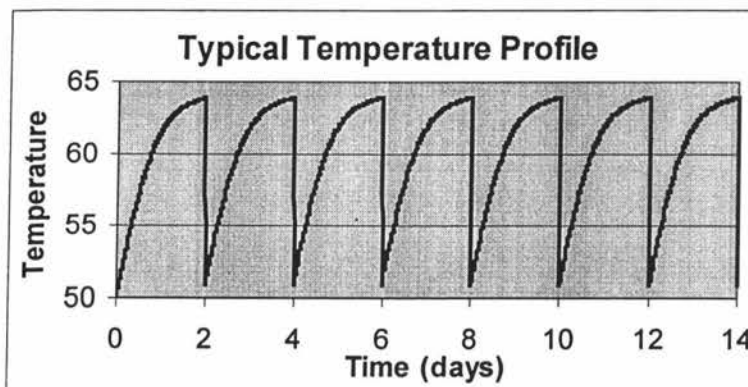


Figure 3 - A typical temperature profile of a semi-continuous ATAD reactor.

A full batch process is where a reactor is completely filled with raw sludge and aerated for several days, until the stabilisation and disinfection criteria is met. The reactor is then emptied and the process repeated. The downfall of this type of operation is each batch has to pass through the mesophilic temperature range into the thermophilic temperatures, where reaction rates are significantly slower.

A semi-continuous system is where a small portion of the sludge is removed from the reactor once it has met the stabilisation and disinfection criteria and then the reactor is topped up with raw sludge. This type of operation prevents the temperature dropping back into the slower mesophilic region, but it still results in large variation in operating conditions.

It is quite common to build an a ATAD process with multiple tanks in series as the first reactor absorbs the majority of the temperature fluctuations, and allows the following reactors to maintain a more consistent temperature, as a result the following reactors are more stable. With multiple tanks in series the process begins to approach the characteristics of a continuous process, which is discussed in more detail in Section 7.4.

2.3 Variations in the ATAD Process

There are two basic types of ATAD processes, the pre-ATAD system and the conventional ATAD system. The conventional ATAD system requires retention times of between 6 and 10 days, while a pre-ATAD has very short retention times of between 2 and 3 days. This thesis predominately investigates the design, operational and control issues associated with the conventional ATAD system.

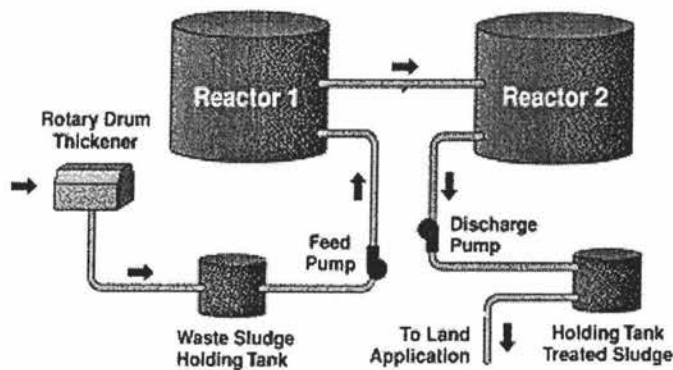


Figure 4 – Typical conventional ATAD configuration

The conventional ATAD operation is where the ATAD system is the last stage of a sludge treatment process; therefore disinfection and stabilisation are key process requirements. Figure 4 shows a typical conventional ATAD system with two ATADs

in series. They can be built with a single reactor or many more reactors in series. The design used depends highly on the sludge loading.

As shown in Figure 5 a typical pre-ATAD system is placed before an anaerobic treatment process. The main objective of this type of operation is to disinfect the sludge but only a small amount of the Volatile Solids are stabilised. A pre-ATAD has very short retention times (2-3 days) as the subsequent anaerobic process will stabilise the sludge further and obtain the methane from the process. Additional heat is often required in a pre-ATAD system, as insufficient heat is released by the biochemical reaction to maintain the thermophilic temperatures.

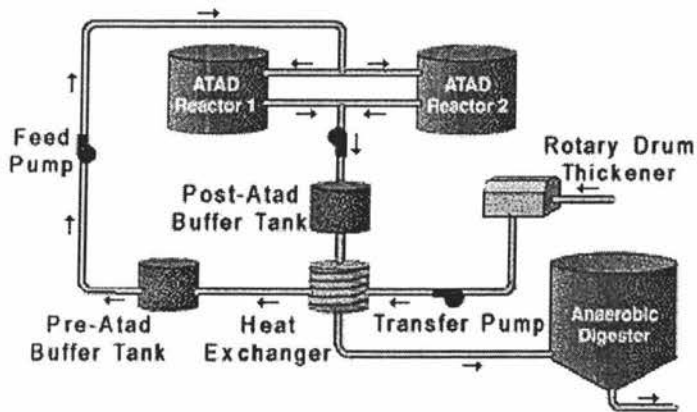


Figure 5 – Typical Pre-ATAD configuration

An additional benefit of a pre-ATAD system is the ability to extend the life of an existing overloaded anaerobic digester, as well as producing sludge that meets Class A biosolid standards. Pagilla *et al.* (1996) found that a pre-ATAD is capable of reducing *Nocardia* bacteria populations in waste activated sludge and hence prevent foaming in subsequent anaerobic digesters. McIntosh and Oleszkiewicz (1997) found that a pre-ATAD process is capable of producing large quantities of short chain volatile fatty acids (VFA) under oxygen limited conditions, which could be used as a carbon supplement for denitrification.

2.4 Oxygen Transfer in an ATAD process

Oxygen is required to stimulate the oxidation reaction in an ATAD reactor. Oxygen is usually supplied by entraining air into the sludge with the aid of some

aeration/mixing device. Pure oxygen has been used in the past but air is now the most popular source of oxygen for an ATAD.

When the concept of ATADs was first approached it was thought that oxygen levels in the sludge of an ATAD reactor are difficult to maintain, due to the reduction in saturation values of oxygen in water at high temperatures. It was therefore thought that pure oxygen would be required to supply sufficient oxygen to the process as air would cool the system too much, but it was soon proved not to be the case.

High temperatures cause a decrease in liquid viscosity, which allows the rate of oxygen transfer to be higher because of an increase in the coefficient of molecular diffusivity of oxygen (Surucu G.A., *et al* 1976). Figure 6 shows how a large increase in the coefficient of oxygen diffusivity offsets the decrease in the saturation values of oxygen at high temperatures, resulting in an overall increase of oxygen transfer ability. Due to the large number of variables associated with aeration of sludge Figure 6 was normalised about the maximum oxygen transfer temperature of 70°C so no misinterpretation of the result could occur.

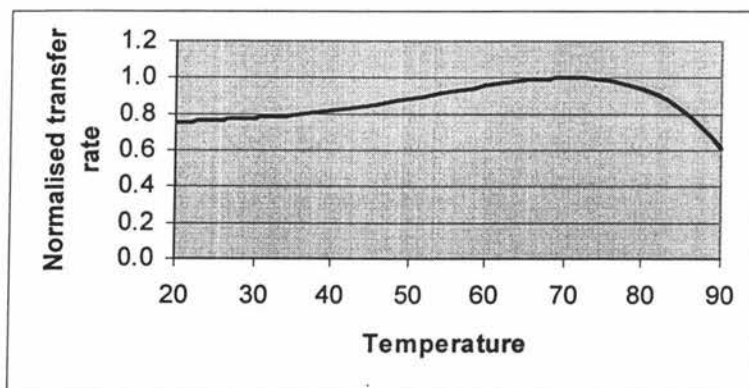


Figure 6 – The effect of temperature on the ability to transfer oxygen into sludge

The reason why it is difficult to maintain a high level of dissolved oxygen in an ATAD process is due to the increased bacteria growth rates at thermophilic temperatures. Therefore the oxygen demand of the microorganisms often exceeds the oxygen supplied. The oxygen levels are generally too low to allow normal aerobic

biochemical reactions to proceed, which results in a unique biochemical process often called a micro-aerobic process.

Typical wastewater aerators seldom have oxygen transfer efficiencies over 5% at ambient temperatures (Jewell and Kabrick, 1980), while ATAD systems have been known to be able to get oxygen transfer efficiencies as high as 100% (Wolinski, 1985), but oxygen transfer rates between 15 and 40% are more realistic. The reason for the higher transfer efficiencies in ATAD sludge is a combination of both very low oxygen levels in the sludge and the increased ability of transferring oxygen at elevated temperatures.