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OPERATION OF AN ACTIVATED SLUDGE PLANT FOR FELLMONGERY WASTEWATER TREATMENT

A thesis submitted in partial fulfilment of the
requirements for the degree of

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ABSTRACT

Activated sludge is one of the most common wastewater-treatment processes used to reduce pollutant loads on the receiving environment. For efficient operation, there must be an effective process control and operation strategy in place to ensure that process problems are avoided. This research is a case study into the process control and operation of an activated sludge plant used for fellmongery wastewater treatment.

Analysis of the pretreated fellmongery wastewater showed that it is characterised by high total and volatile suspended solids concentrations, and high organic nitrogen concentrations. The plant was experiencing frequent problems that were attributed to the high influent suspended solids load coupled with ineffective solids management.

Operation of bench-scale simulations showed that solids retention time (SRT) control at 5 or 10 days will produce acceptable effluent suspended solids concentrations and soluble chemical oxygen demand (COD) removal. Soluble COD removal for both 5 and 10 days was high at 85 and 80 % respectively at a hydraulic retention time of 6.4 days. Effluent suspended solids concentrations were 100 and 157 g/m³ respectively.

A steady state control model was developed based on, mass balances of biochemical oxygen demand (BOD) and volatile suspended solids (VSS), process performance equations, and the solids retention time (SRT). The model used three control points, the clarifier underflow pump, the clarifier influent pump and the waste sludge pump. The model was incorporated into an off-line Activated Sludge Operation Program (ASOP) to provide a user-friendly interface between the plant and operator. The main output from ASOP includes values for the three control points and suggestions to help avoid problems. A process control and operation strategy was developed using ASOP, the knowledge gained in this research, and an operation manual developed from accepted operation practises.

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LIST OF SYMBOLS

Q	= Influent wastewater volume (m^3/d)
S_o	= Influent organic matter concentration ($\text{g COD or BOD}/\text{m}^3$)
S	= Effluent organic matter concentration ($\text{g COD or BOD}/\text{m}^3$)
X	= Activated sludge reactor biomass concentration ($\text{g VSS}/\text{m}^3$)
V	= Activated sludge reactor volume (m^3)
Q_w	= Waste activated sludge volume (m^3/d)
r_{su}	= Organic matter removal rate ($\text{g COD or BOD}/\text{m}^3.\text{d}$)
μ_m	= Maximum specific growth rate (days^{-1})
K_S	= Half-velocity constant (g/m^3)
Y	= Biomass yield ($\text{g VSS}/\text{g COD or BOD}$)
k_d	= Endogenous decay coefficient (day^{-1})
r_g	= Net biomass generation rate ($\text{g VSS}/\text{m}^3.\text{d}$)
F/M	= Food-to-microorganism ratio ($\text{g COD or BOD}/\text{g VSS}.\text{day}$)
HRT	= Hydraulic retention time (days)
X_V	= Mixed liquor volatile suspended solids concentration ($\text{g VSS}/\text{m}^3$)
E_S	= Organic matter removal efficiency (%)
R_S	= Organic matter removal rate ($\text{g COD or BOD}/\text{d}$)
WAS	= Waste activated sludge mass ($\text{kg TSS}/\text{d}$)
V	= Volume of the reactor (m^3)
X_{CURRENT}	= Current mixed liquor suspended solids concentration ($\text{g TSS}/\text{m}^3$)
X_{TARGET}	= Target mixed liquor suspended solids concentration ($\text{g TSS}/\text{m}^3$)
SMP_{nd}	= Non-degradable soluble microbial products
SRT	= Solids retention time (days)
Q	= Effluent flowrate (m^3/d)
G_{VSS}	= Net biomass generation rate ($\text{g VSS}/\text{d}$)
F	= Initial filter dry weight (g)
$(F+R_1)$	= Filter plus primary residue dry weight after evaporation at 105°C (g)
V_S	= Sample volume (ml)
$(F+R_2)$	= Dry weight of the filter and the residue left after ignition at 550°C (g)
SSV_{30}	= Settled sludge volume after 30 minutes (ml)
$MLSS_2$	= Mixed liquor suspended solids concentration in basin two ($\text{g TSS}/\text{m}^3$)
SVI	= Sludge volume index ($\text{ml}/\text{g TSS}$)
BOD_t	= Biochemical oxygen demand for time t ($\text{g BOD}/\text{m}^3$)
t	= Time (days)
COD	= Chemical oxygen demand ($\text{g COD}/\text{m}^3$)

1 INTRODUCTION

1.1 BACKGROUND

The main task of a fellmongery is to process raw animal skins from local slaughterhouses to produce preserved pelts, which are sold to local and offshore tanneries for making leather. The fellmongery process also produces significant quantities of high strength wastewater that is usually pretreated and then discharged to a local sewer. This study is concerned with optimising the operation of the Richmond fellmongery (Shannon) activated sludge plant.

The activated sludge process is a continuous system that involves a mixed population of microorganisms that remove pollutants from a wastewater solution for growth and other cellular processes. Activated sludge is difficult to control in reality because there are many parameters that influence process performance and effluent quality, which is a reflection of it being a biological process. Control and operation of activated sludge also depends on the type of wastewater and its relative biodegradability. Therefore, unless the operator understands how a particular activated sludge plant performs under different conditions, the process may periodically fail.

Figure 1.1 is a schematic representation of the Richmond activated sludge plant. The function of this plant is to reduce the organic and solid loadings of the pretreated fellmongery wastewater in order to meet the effluent-quality limits listed in Table 1.1. These levels were set by the fellmongery as performance targets to ensure that the effluent is well below the related resource-consent limits.

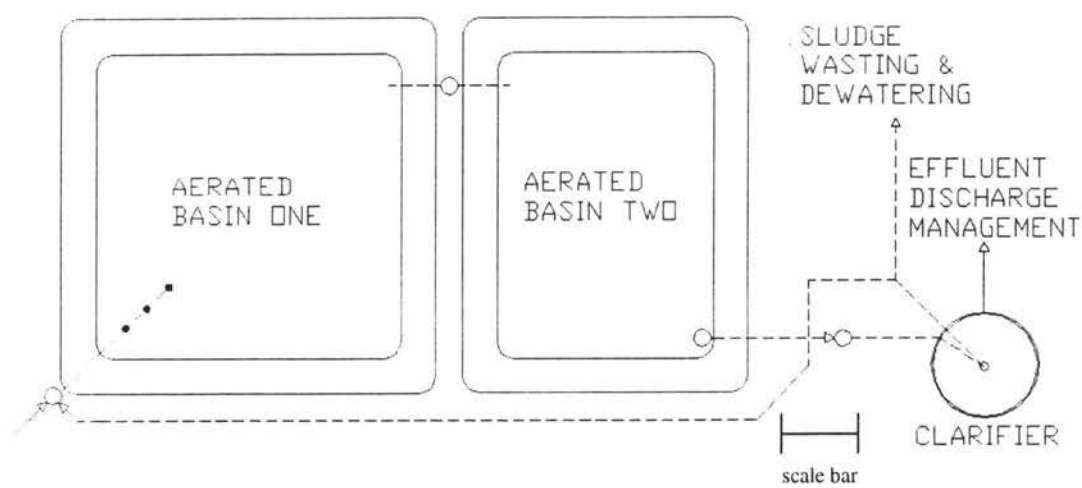


Figure 1.1: The fellmongery activated sludge plant (scale bar = 8.6 m).

Characteristic		Target (kg/d)
Biochemical oxygen demand	BOD	450
Total suspended solids	TSS	900
Ammonia	Ammonia	540

Table 1.1: Effluent quality targets for total suspended solids, biochemical oxygen demand and ammonia.

The effluent quality targets (except BOD) are frequently exceeded due to process problems that often lead to poor effluent quality. These process problems were attributed to an inadequate process control and operation strategy and large variations in the pretreated fellmongery wastewater-characteristics.

1.2 PRIMARY AIM

The primary aim of this project was to characterise the pretreated fellmongery wastewater and provide the fellmongery with a refined process control and operation strategy for their activated sludge plant.

1.3 THE PROJECT TASKS

1.3.1 Task 1: Characterise the fellmongery wastewater and diagnose observed process problems in the activated sludge plant

Task 1 was based on the first objective to obtain data on particular wastewater characteristics and diagnose process problems with possible solutions. The wastewater characteristics measured were those that were known to be important for successful activated-sludge operation.

1.3.2 Task 2: Evaluate solids retention time control (SRT) using bench-scale simulations

The objective of this task was to use bench-scale simulations of the fellmongery activated-sludge plant, to obtain data on Solids Retention Time (SRT) control. SRT was chosen as the central control parameter due to its current popularity and relationship to microbial growth rate.

1.3.3 Task 3: Develop a steady-state mathematical model of the activated-sludge plant

The objective of task 3 was to generate a simple mathematical model for describing the biochemical and physical operations occurring in the fellmongery activated-sludge plant. During development, the critical process-control points were identified and included in the model.

1.3.4 Task 4: Develop a new process-control and operation strategy

The objective of task 4 was to construct and refine the new process-control and operation strategy using results from tasks 1, 2 and 3. The strategy was to be embodied in a user-friendly computer program.

1.4 THE FELLMONGERY PROCESS

1.4.1 Introduction

The Richmond fellmongery (Shannon) processes sheep and lamb-skins, to produce preserved pelts and wool for local and offshore tanneries and garment manufacturers. A basic block diagram of the fellmongery process is shown in Figure 1.2. In New Zealand, the fellmongery

process usually stands alone from the tannery, which is a carryover from the days when New Zealand was a major player in exporting associated meat products (Ryder, 1976). In 1976, New Zealand was ranked as the third largest producer of fellmongered pelts in the world (Aloy *et al*, 1976). More recently, New Zealand ranks second and produces 30 % of the world's garment leather material.

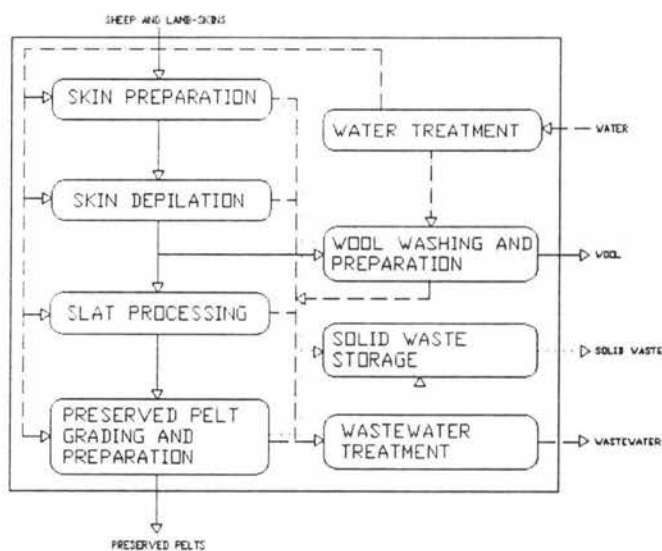


Figure 1.2: A block diagram of the fellmongery process showing flows of water, wastewater and solid waste.

1.4.2 The Animal Skin

In general, an animal skin can be divided into three main parts: the epidermis, the dermis, and the flesh layer as shown schematically in Figure 1.3.

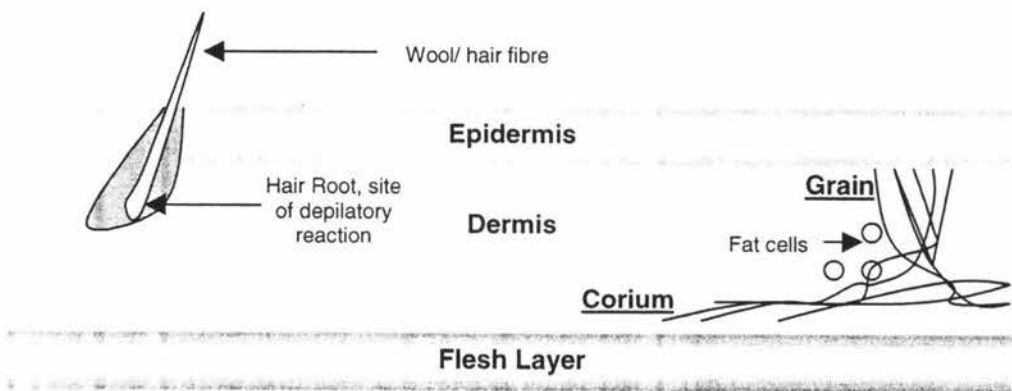


Figure 1.3: A simple diagram illustrating the general parts of a typical animal skin.

1.4.3 Skin Preparation

The aim of Skin Preparation is remove the flesh layer and excess fluid from the skin so as to expose the corium side of the dermis. Flesh and related solids are discarded to solid waste. Wastewater consisting of blood, fat and salt is generated.

1.4.4 Skin Depilation

Skin Depilation involves application of the depilatory paint to the exposed corium. This removes wool and hair at the root and exposes the epidermis. The depilatory paint is made from sodium sulphide (Na_2S , depilatory agent), caustic soda (NaOH , for alkalinity) and hydrated lime ($\text{Ca}(\text{OH})_2$, a thickener). Wasted paint is drained away and directed to wastewater treatment along with the wastewater from Skin Preparation.

1.4.5 Wool Washing and Preparation

Wool recovered from Skin Depilation is sorted and taken by trolley to the wool washer. The wastewater generated is pretreated to remove excess wool and gross solids and then mixed with the wastewater from the previous unit processes. Washed wool is fed to the Wool Drier, which uses dry air to remove excess moisture from the wool. The dried wool is stored in lots and graded before it is packed for export.

1.4.6 Slat Processing

The skins now referred to as slats (skins minus wool) enter the Slat Processing stage. The "slat processors", usually referred to on the fellmongery-floor as the "challenge cooks" are huge rotating drums that process up to 7.5 tonnes of slats in one setting (cf. concrete mixer). The slats are processed in these rotating drums for eight hours to remove the epidermis and extraneous matter to expose the grain side of the dermis. The grain is the most important part of the skin because it will provide the sheen to a high-grade leather product. The slat processors are operated in three main steps.

1.4.6.1 Step 1: Liming

The first step is referred to as liming, because the original agent used was lime ($\text{Ca}(\text{OH})_2$). The liming step involves dosing a load of slats with a sodium sulphide/water float for up to three hours to remove persistent wool fibres and pulp hair from the grain. The sodium sulphide/water float recipe for liming will depend on the slat type (sheep or lamb), and may

change in response to poor depilation. After liming is complete, the processor is pumped down and washed out several times with water to remove the used liming liquors.

Collagen is a fibrous protein that occurs in long threads, it is water insoluble and it is the main constituent of the fibres that make up the dermis layer. During slat processing the skin “opens up” because the collagen fibres absorb water to “plump” or “swell” in the alkaline medium (Carrie *et al*, 1960). Mucins are non-fibrous proteins and form the interfibrillary tissue filling the spaces in the network of collagen fibres (Carrie *et al*, 1960). Mucins are insoluble in water and will swell; liming will dissolve them however so they can be removed in the wastewater (Carrie *et al*, 1960).

1.4.6.2 Step 2: Delime

Once the lime washouts are completed, deliming commences to remove persistent sulphide and residue from the processor and reduce the alkalinity. Delime uses carbon dioxide as a neutralising agent. CO₂ dissolves in water to form a carbonic acid (HCO₃⁻) buffer solution that stabilises the pH at around 8-9 units. During deliming significant amounts of hydrogen sulphide evolves as the pH is reduced. Hydrogen peroxide (H₂O₂) is added intermittently as a counter agent to oxidise the H₂S and reduce risk.

1.4.6.3 Step 3: Bating

The third step called bating uses pancreatic enzymes to open the fibre structure of the pelt so that the grain is fully cleansed of detritus (Massey University Dept. of Biotechnology, 1976). Bating will only succeed if the delime step manages to stabilise the pH to between 8 and 9 (Carrie *et al*, 1960).

1.4.6.4 Step 4: Pickling

The pelts are finally subjected to the pickle step, which involves addition of sulphuric acid and salt. The acidic/ saline medium does not support microorganisms so the pickling step produces a pelt resistant to biological degradation and ready for the tannery. However, the mould *Alternaria tenuis* can find a pickled pelt nourishing, and is recognised as a dark-green almost black mould (Massey University Dept. of Biotechnology, 1976). Busan is added during this step as a fungicide to protect the pickled pelt from fungal degradation (Massey University Dept. of Biotechnology, 1976). The pickled pelts are unloaded from the processors

into the pickle troughs. Once in the troughs, the pickled pelts are allowed to soak in the pickle until the pelt-graders are ready.

1.4.7 Preserved Pelt Grading and Preparation

The pickled (preserved pelts) are removed from the trough by hand, and the pickle is drained to wastewater treatment. Pickled pelts are graded according to the quality of the grain and the amount of residual wool. The graded pelts are pressed to squeeze out excess fluid and reduce volume for export. This is another source of wastewater especially when the grading floor is washed down with fresh water. Finally, the preserved pelts are heat packed ready for export.