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***A Conductivity Probe for Thickeners:  
Calibration and Level Estimation***

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***A thesis submitted to the Faculty of Graduate Studies and  
Research in partial fulfilment  
of the requirements for the degree of  
Master of Engineering***

***Department of Mining and Metallurgical Engineering  
McGill University, Montreal, Canada***

**July, 1998**

**@ Jolanda Vergouw, 1998**



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***This work is dedicated to my parents  
for their love,  
encouragement  
and support.***

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# ABSTRACT

Thickening is the separation of suspended solid particles from a liquid by gravity settling. As a feed stream enters the thickener, the solids settle to the bottom. Clarified liquid overflows the top and the settled solids (underflow) is removed. Thickeners are widely used in the minerals and metal processing industry.

To assist in the monitoring and control of thickeners a conductivity probe has been developed. Test work was carried out on a concentrate thickener at the Copper Cliff, Ontario Division of Inco Limited in Sudbury.

The conductivity probe is a multicell arrangement. It exploits the difference in conductivity between liquid, slurry and settled solids. A conductivity profile is collected which locates the interfaces (liquid/slurry, slurry/settled solids) by detecting the change in conductivity. The conductivity profile can be readily converted to a solids concentration profile using a model due to Maxwell. From the solids profile, a solids inventory are obtained along with an estimation of underflow density. The main tasks in this thesis were to a) develop a method of on-line calibration and b) develop a level estimation procedure. The former was achieved by designing a portable probe and lowering it in to predetermined positions corresponding to rings on the probe. The time between re-calibration was also established (ca. 10 days). In the case of the level a previous method using a 0-1 scale has been converted to a true bed height using the bed height estimated by the operators using a weighted rope.



Some parameters influencing thickener behaviour were also monitored. A relationship was explored between the % solids in the overflow and the flocculant rate. A higher flocculant rate results in less solids reporting to the overflow. However, this relationship is not valid for excess flocculant addition, in which case fine solids also report to the overflow. Excess flocculant addition also results in a compacted bed with a high torque.

The next stage in the development of the probe would be the modelling of the parameters that influence thickener behaviour using the conductivity probe. The model should improve the operational efficiency of industrial thickeners.

# RÉSUMÉ

L'épaississement est la séparation de particules solides en suspension, d'un liquide sous l'effet de la gravité. Lorsqu'une alimentation entre dans l'épaississeur, les solides se déposent au fond. Un liquide clair surverse au-dessus et les solides déposés (sousverse) sont retirés. Les épaisseurs sont largement utilisés dans l'industrie des procédés de minerais et métaux.

Afin d'assister la surveillance et le contrôle des épaisseurs, une sonde de conductibilité a été développée. Les tests ont été conduits sur un épaisseur de concentré à Copper Cliff, Division Ontario d'Inco Limité à Sudbury.

Le sonde de conductibilité est un arrangement de multi-cellules. La base en est la différence de conductibilité entre un liquide, une suspension et des solides déposés. Un profil de conductibilité est produit afin de situer les interfaces (liquide/suspension, suspension/solides déposés) en détectant les changements de conductibilité.

Le profil de conductibilité peut être directement converti à un profil de concentration de solides en utilisant un modèle de Maxwell. À partir d'un profil de solides, un inventaire de solides ainsi qu'une estimation de la densité à la sousverse sont obtenus. Les objectifs principaux de cette thèse furent a) développer une méthode de calibration en direct et b) développer une procédure d'estimation du niveau. Ce dernier objectif a été réalisé par la conception d'une sonde portable abaissée à des positions prédéterminés correspondants aux bagues sur la sonde. Le temps entre la re-calibration fut aussi établi (ca. 10 jours). Dans le cas du niveau, une échelle de 0-1 a été convertie à un niveau de lit exact un utilisant la hauteur de lit estimée par les opérateurs utilisant un poids au bout d'une corde.

Certains paramètres influençant le comportement de l'épaississeur furent aussi contrôlés. Une relation fut explorée entre le % de solides à la sousverse et le taux de flocculant. Un taux de flocculant plus élevé résulte en une baisse de solides se retrouvant à la sousverse.

Cependant, cette relation n'est pas valide lors d'une addition excessive de flocculant, cas où des solides fins se retrouvent aussi à la sousverse. Une addition excessive de flocculant résulte aussi en une compacité du lit avec un torque élevé.

La prochaine étape dans le développement de la sonde serait le modèle des paramètres influençant le comportement de l'épaississeur au utilisant la sonde de conductibilité. Le modèle devrait améliorer l'efficacité opérationnelle des épaisseurs industriels.

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# LIST OF SYMBOLS

## Conductivity

<u>symbol</u>	<u>description</u>	<u>unit used</u>
V	voltage	V
I	current	A
R	resistance	$\Omega$
J	current density	A/cm <sup>2</sup>
$\lambda$	electrical conductivity	mS/cm
$\Lambda$	conductance	mS
E	field intensity	V/cm
$\delta$	resistivity	$\Omega$ cm
l	distance between points where voltage is measured	cm
A	cross sectional area perpendicular to the direction of current	cm <sup>2</sup>
$\epsilon_d$	solids holdup	-
$\lambda_{1-d}$	conductivity of dispersion	mS/cm
$R_{1-d}$	resistance of dispersion	$\Omega$
$\lambda_l$	conductivity of liquid	mS/cm
$\alpha$	temperature coefficient of conductivity	cm/ $^{\circ}$ C
$\Delta T$	difference between measured temperature and 25 $^{\circ}$ C	$^{\circ}$ C

**Thickener**

<b><u>symbol</u></b>	<b><u>description</u></b>	<b><u>unit used</u></b>
SD	specific gravity of solids	$\text{g/cm}^3$
SV	volume percentage of solids	$\text{cm}^3$
LD	specific gravity of liquid	$\text{g/cm}^3$
% w/w	weight percentage of solids	-
% v/v	volume percentage of solids	-
V(x)	volume of a ring at a given depth x	$\text{cm}^3$
S(x)	mass percentage of solids	
h	interval between measurements corresponding with thickness of ring on industrial probe	s
D	diameter of thickener	m
r	radius of thickener	m
H	height of cone	m

# CHAPTER 1

## INTRODUCTION

There are many examples in mineral processing where the operation of equipment cannot be optimized because some of the most important variables are poorly sensed. These include thickener operations. Thickening is the separation of suspended solid particles from a liquid by gravity settling. As a feed stream enters the thickener, the solids settle to the bottom. Clarified liquid overflows the top and the settled solids (underflow) are removed from the bottom.

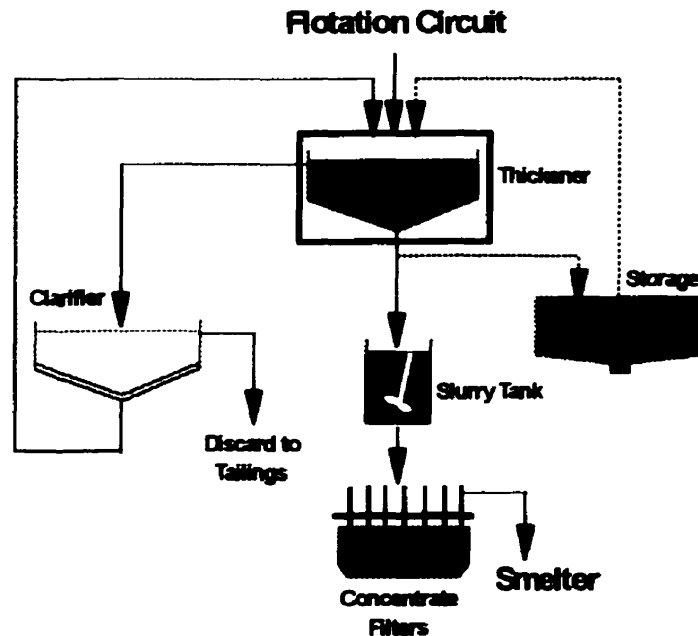


Figure 1.1: Flowsheet of thickener circuit at Copper Cliff, Ontario Division of Inco Limited..

A flowsheet of the flotation concentrate thickener circuit at the Copper Cliff Ontario Division of Inco Limited, Sudbury, is given in Figure 1.1. All test work discussed in this thesis was done at thickener 1A of this circuit. In total there are five thickeners, however not all of them are operational. Typical concentrate assays are given in Table 1.1 and can vary  $\pm 5\%$ . The underflow goes to a slurry mixing tank to prevent the slurry from compacting, as otherwise it causes difficulties in pumping to the filters. Sometimes flocculants are added to the slurry tank to aid filtration. Some slurry may be directed to the storage, which is reclaimed when the product from the flotation circuit is not sufficient to feed the thickener. From the slurry tank the slurry goes to the filters from where the product is fed to the smelter. The overflow from the thickener is directed to a clarifier, from where the overflow goes to the tailing area and the underflow is redirected to the thickener feed.

Table 1.1: Elements/minerals in the feed of thickener 1A at Copper Cliff, Ontario Division of Inco Limited.

Elements / Minerals								
	Cu	Ni	S	Cp	Po	Pn	Rk	Po/Rk
%	9.4	9.4	29.5	27	29	26	17	1.8

Cp, chalcopyrite; Po, pyrrhotite; Pn, pentlandite; Rk, rock

## 1.1 Problems in thickener operation

In practice various problems can occur in the thickening process. It is therefore important to control the several variables that influence thickener behaviour. For example the underflow density (percent solids) from the thickener has to be in a certain range for the filters. The percent solids should not be too low since that increases filtering costs, nor should it be too high as the pumps have difficulty transporting the material. To measure underflow density the practice at Copper Cliff, Ontario Division of Inco Limited, is to take a sample and use a Marcy density meter. This, however, is time consuming, and the



underflow pipe where the sample has to be taken is not easily accessible. There are sensors to measure underflow density, the most important being the Gamma-Ray density gauge [1]. However they are not without problems, for example they can become plugged. Therefore it is essential to develop a method to give underflow density accurately at any time that is not labour intensive.

An operational requirement is to avoid a dirty overflow. At this particular thickener at Inco a dirty overflow occurred several times during the test period causing revenue loss. To prevent this loss the settling of solids in a thickener should be monitored.

Little is known about the behaviour of particles and liquid inside a thickener. The lack of fundamental data has hindered the development of reliable models. Most models are based on empirical, black-box approaches. Such approaches can be quite satisfactory for routine design and steady-state simulation purposes, provided that a substantial experimental database is available. The expanding role computing is playing will mark an important development in data acquisition and modelling. Development of on-line sensor technology will also expand. In one approach Williams et. al. [2-4] are developing on-line instrumentation using tomography. This thesis examines the use of a conductivity-based probe.

## 1.2 Objectives of project

The main objectives of this thesis are:

- ☞ Devise procedure for calibrating conductivity probe and determine how often the probe has to be calibrated.
  
- ☞ Develop method to give actual bed height (i.e., in feet or centimetres), so it can be

monitored continuously and action can be taken in time if it should rise too high or fall too low.

☞ Change the Quick Basic program which is currently used for data acquisition to a Visual Basic program to make the program more accessible to the operators.

With solutions to the above objectives met, the study of operating variables can commence such as:

☞ The influence of pH and flocculant rate on settling rate and quality of the overflow.

☞ The variation in inventory with operating conditions.

The eventual aim is a model of thickener behaviour describing interaction among:

torque ↔ flocculant rate

bed height ↔ load ↔ torque

### 1.3 Methodology

To achieve the objectives the following methodology was used. Exploiting the difference in conductivity between clear liquid and slurry a conductivity probe has been developed [5-10]. One probe has been installed in a thickener at Copper Cliff, Ontario Division of Inco Limited operation since October 1994. The probe consists of 32 rings, which give conductivity as a function of depth, called a conductivity profile. A typical profile, Figure 1.2, shows the location of the liquid and the solids bed. Due to deposition on the rings the probe has to be calibrated periodically. Different methods for calibration were investigated. The length of time between calibration was deduced by comparing the profiles

over time and judging at what point the deviation had become too large.

After a satisfactory calibration procedure had been found the profiles were used to determine bed height from the location of the change in conductivity. Probst et. al. [8-10] devised a scale of 0-1 for bed height using the profile. The operators did not find this convenient. The bed height is usually measured by the operators with a weighted rope (manual method). Not only is this not compatible with automation, in winter these manual measurements are not possible due to ice forming on the thickener. A correlation is established between the 0-1 level deduced from the conductivity profile and the bed height given by the manual method. Correlation with the manual method is used because it is trusted by the operators. Other methods to measure bed height from the conductivity profile were also tested.

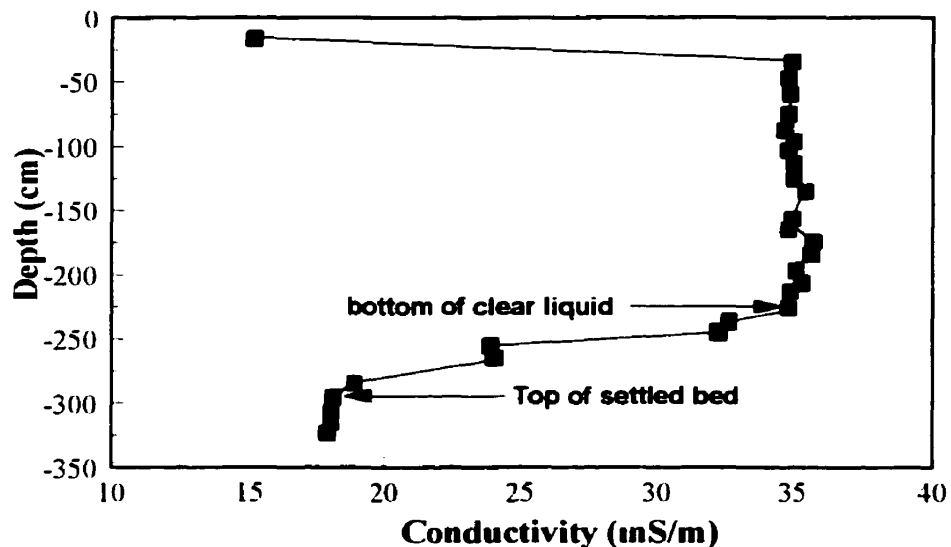


Figure 1.2: Example of conductivity profile (conductivity vs. depth).

Conductivity can be converted to % solids using an appropriate form of Maxwell's model. This can be used to estimate the underflow density and to give the total load or inventory (tonnes of solid) in the thickener.

Several parameters that influence thickener behaviour were monitored over an extended period of time. The pH and % solids in the overflow (which were directly measured from samples) were monitored together with the flocculant rate. The mutual interdependence of flocculant rate, bed height, load, torque and resulting thickener performance was studied.

A start was made to change the data acquisition software from Quick Basic to Visual Basic. Emphasis was put on the data read-in which is different from Quick Basic. The parameters, load and bed height, are displayed continuously on-line along with a profile of % solids vs. depth.

## **1.4 Outline of thesis**

The objectives of the project and the methodology are given in chapter 1 together with the structure of the thesis.

In chapter 2 an overview of thickeners is given. The background and a brief review on the use of conductivity to detect interfaces is also given. A brief theory of conductivity is included.

The experimental setup of a multicell conductivity probe (the stationary probe) is discussed in chapter 3, together with the maintenance of the probe. The data acquisition program written in Quick Basic and the new version in Visual Basic are discussed. The use of a single cell portable probe for calibration is introduced.

Chapter 4 outlines several calibration procedures for the stationary probe. Two procedures (standardization- and portable probe method) are discussed in detail.

Results obtained with the industrial probe are given and discussed in chapter 5. This chapter focusses on the detection of the mud-line. The signal from the probe is compared with manual bed height measurements with a weighted rope.

Observations on thickener behaviour is the focus of chapter 6. The relationship between torque and flocculant rate addition is discussed together with their relationship to overflow quality. Third, a relationship between % solids in the overflow and flocculant rate and pH is shown along with a method is given to predict the % solids in the overflow. To end a start is made to model the influence on of bed height, torque and feed rate on each other and on general performance of the thickener.

Conclusions and suggestions for future work are given in chapter 7.

# CHAPTER 2

## BACKGROUND

In this chapter the thickening process and the various, commonly used thickeners are discussed. This is followed by a literature review of bed height measurements and the use of conductivity in the mineral processing industry especially its ability to detect interfaces. An introduction to conductivity is then given followed by the use of conductivity in a thickener.

### 2.1 Introduction

Thickening is the separation of suspended solid particles from a liquid by gravity sedimentation. It is the most widely applied dewatering technique in mineral processing for many reasons. Thickeners are cheap for their capacity and involve low shear forces, thus generally providing good conditions for flocculation of fine particles. The ideally operated thickener gives two products: an underflow of target % solids and a clear overflow.

## 2.2 Thickener types

### 2.2.1 Mechanical thickeners

The diameter of these thickeners is usually large compared to the depth, and therefore a large foot print is required. Mechanical thickeners are often encountered to prepare gold ores for cyanidation and for flotation concentrates to prepare for shipment or filtration. These devices are also referred to as mechanical settlers. The thickener used for the test work at Copper Cliff, Ontario Division of Inco Limited, is a mechanical settler.

Mechanical thickeners, having a shallow cone angle, are provided with rakes which, while not moving at a rate to interfere with settlement, move settled material to the central discharge point before it has time to pack. These rakes are attached to the underside of up to four radial arms. Figure 2.2 displays the rakes of thickener 2A at Copper Cliff, Ontario Division of Inco Limited (there is hardly any material in the thickener as it was emptied into thickener 1A.). Upon each revolution the rakes move settled material to the central discharge. This transport is assisted by sloping the arms about 10 degree downwards towards the centre. For thickeners up to ca. 30 m diameter the design usually includes a bridge and catwalk through the centre of the tank which supports the drive mechanism and the arms (Figure 2.1) [11].

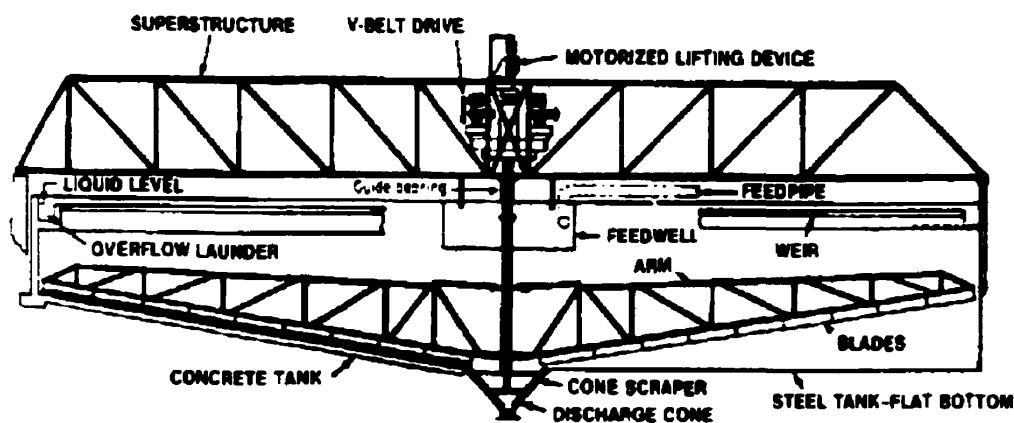


Figure 2.1: Cross section through mechanical thickener with bridge construction.

For thickeners larger than 30 m, a bridge is too costly and a central pier design is used. The central pier carries the weight of the drive mechanism and rake arms as well as the catwalk. The fabrication material is generally steel-reinforced concrete, or suitable corrosion-resistant material. The Copper Cliff, Ontario Division of Inco Ltd., thickener used for the experiments falls in this category.



Figure 2.2: Rake and support structure.

### 2.2.2 Tray thickeners

Tray thickeners are sometimes installed to conserve space (and heat when elevated temperatures are involved). A major user is the alumina industry to settle red muds [11]. In essence, a tray thickener (Figure 2.3) is a series of unit thickeners stacked one above the other. They operate as separate units, but a common central shaft is utilised to drive the rakes [12]. They have also been employed in countercurrent decantation systems [11]. Clear solution or water is taken from the upper layers of each compartment. The material settled on each tray is separately discharged, being generally drawn off by the suction of a pump. In the centre of the upper trays is a feed passage to the lower compartments. As many as six trays can be installed in one tank. Usage has been limited as operating control is more difficult and underflow densities are usually lower than with mechanical thickeners.



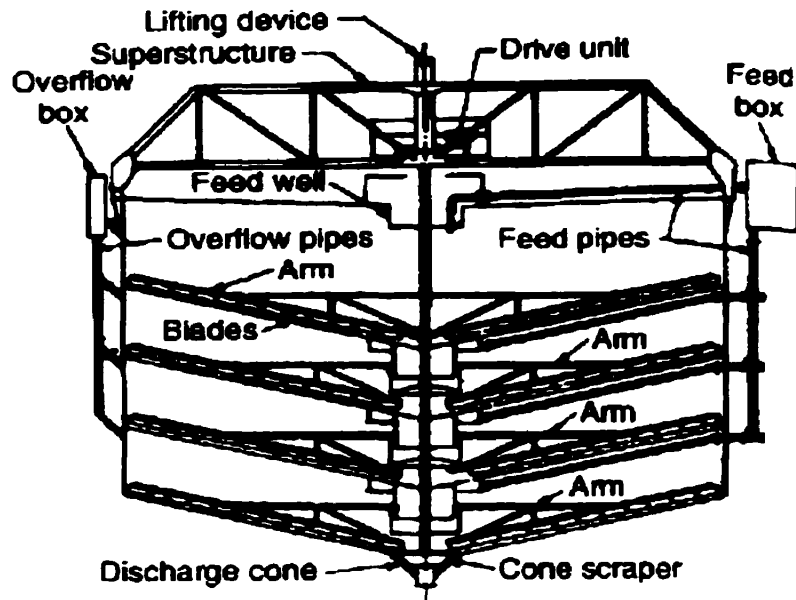


Figure 2.3: Tray thickener (cross-section).

### 2.2.3 High capacity thickeners

Mechanical thickeners suffer from the disadvantage that large floor areas are required. Throughput depends above all on the area, while depth is of minor importance. In recent years, machines known as “high capacity” thickeners have been introduced by companies like Outokumpo and Supaflo. Many varieties exist, but all are typified by low area requirements. Two types of high capacity thickeners will be discussed.

#### *Enviro-Clear thickener*

Envirotech Corporation developed the Enviro-Clear thickener (Figure 2.4) [13]. One of the most important features is the use of stage mechanical mixing of feed and flocculant to improve thickening. Figure 2.4 shows that the feed enters via a hollow drive shaft where

flocculant is added and is immediately dispersed by staged mechanical mixing. The flocculated feed leaves the mixing chamber and is injected into the slurry where the solids of the feed are further flocculated by contact with previously flocculated material.

The Enviro-Clear thickener finds use, for example, for tailings water reclamation. The thickeners occupy an area only 5% that required for mechanical thickeners operating without flocculant [12].

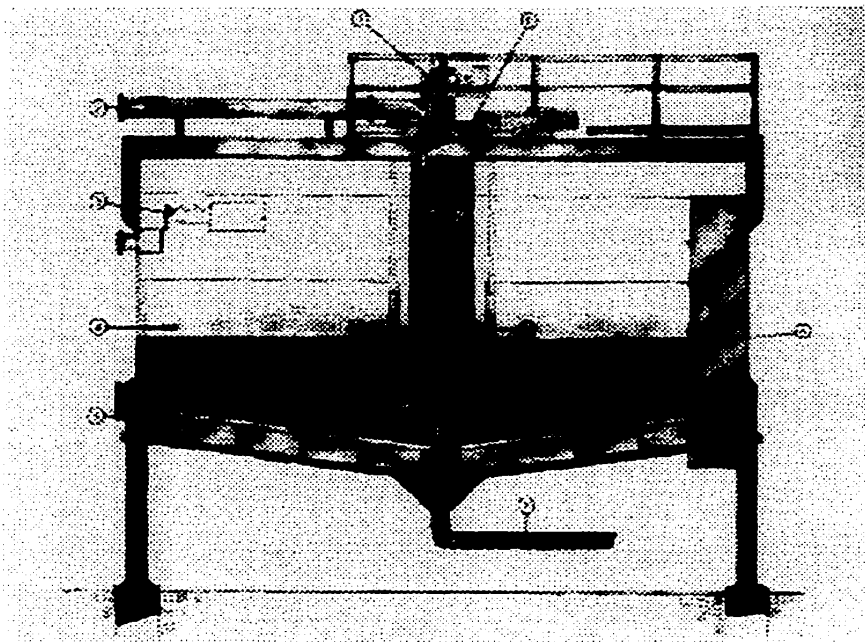


Figure 2.4: Enviro-Clear thickener.

### ***Lamella thickener***

Another method of increasing the effective area of a thickener is to use a nest of inclined baffles or lamella [14]. The inclined parallel plates both reduce settling distance and at the same time increase the effective area. The lamella thickener uses only 20% of the area of a conventional thickener. The theoretical surface is the product of the total area of lamella

and the cosine of the angle of their inclination. The inclined parallel trays allow the settled solids to slide by gravity into a hopper and clear water overflows. The lamella thickener is usually used to treat fine and clay based sludges [12]. The entire lamella pack can be vibrated intermittently or continuously when treating sticky sludges.

#### **2.2.4 High compression thickener**

Sometimes needs arise which require specially designed thickeners. For example, consider the gold pressure oxidation process at Barrick's Goldstrike mine [15]. This circuit is a process bottleneck for a proposed expansion due to the inconsistent underflow density being achieved from the two existing pre-oxidation thickeners. This is mainly due to difficulties in obtaining consistent flocculating conditions with the extremely variable nature of clays in the ore being processed. To make a plant upgrade possible this problem had to be addressed and a high compression thickener was installed which produced a consistently higher underflow density which helped optimize autoclave operation.

The heart of a high compression unit is the feedwell which acts as both a deaerator and flocculant mixing chamber. It uses an autodilution system to keep the density in the feedwell at the optimum level for flocculation irrespective of the feed density or flowrate. The autodilution system takes advantage of the natural head difference across the feedwell wall and controls the flow of supernatant back into the feedwell which acts as dilution water. Thus the need for external dilution water pumps and piping is eliminated. High compression thickeners have been installed throughout the world, many of them doing pre-leach duty in gold circuits. Another example is the Lihir Gold project in Papua New Guinea [15]. A single thickener is used to thicken the grinding mill discharge to 55% solids or higher before preoxidation and pressure autoclaving.

## 2.3 Thickener operation

Clear water can only form from the surface downwards, thus capacity depends upon the extent of the surface area, depth having no effect other than to increase the density of the underflow. Depths of 1.83-3.66 m (6-12 ft) for mechanical thickeners are usually sufficient. Capacity will also depend upon the rate of settlement of the particular pulp.

The surface area requirement for a thickener depends largely on its the function. The surface area for settling flotation concentrate, since any solid in the overflow escaping would mean loss of valuable material, is quite large, typically about  $9.3 \times 10^{-4} - 5.6 \times 10^{-3} \text{ m}^2/\text{kg}$  (10-60  $\text{ft}^2$  /ton) of concentrate per 24 hours.

The settling rate of solids depends on many factors. It varies with the physical and chemical characteristics of the solid in suspension. The rate of settlement depends upon the coagulating effects either of impurities in the water or of agents added. Sulphuric acid and calcium chloride can promote settlement. Alkalis act as dispersants, though when present in small quantities they may have a coagulating effect. Many organic acids are dispersants under all conditions of concentration, promoting the formation of permanent suspensions [14]. The settling rate can also be increased by addition of polyelectrolytes (flocculants); this will be discussed in chapter 6.

Sedimentation depends upon the temperature. An increase in temperature decreases viscosity, thereby increasing the settling rate. In many plants differences in operation between winter and summer have been reported, the capacity of a plant for effective settlement may vary as much as 20% with the season. Settling rate also varies with the density of the pulp. A dilute pulp is generally considered to settle faster than a thick pulp. The particles of the former settling freely, while particles from the latter suffer from hindered settling. This statement, however, does not imply that a given amount of solids would be best settled by diluting the pulp, but only, that of two pulps one thick and the other dilute,

clear water could be drawn at a quicker rate from the dilute pulp than from the less dilute pulp.

### 2.3.1 Zones in thickener

Particles settle in four different regimes: individual particulate settling, flocculant settling, mass settling, and compression settling [11]. The zones are schematically depicted in Figure 2.5. The occurrence of the four regions is dictated by feed dilution and the tendency of particles to agglomerate with or without addition of flocculant.

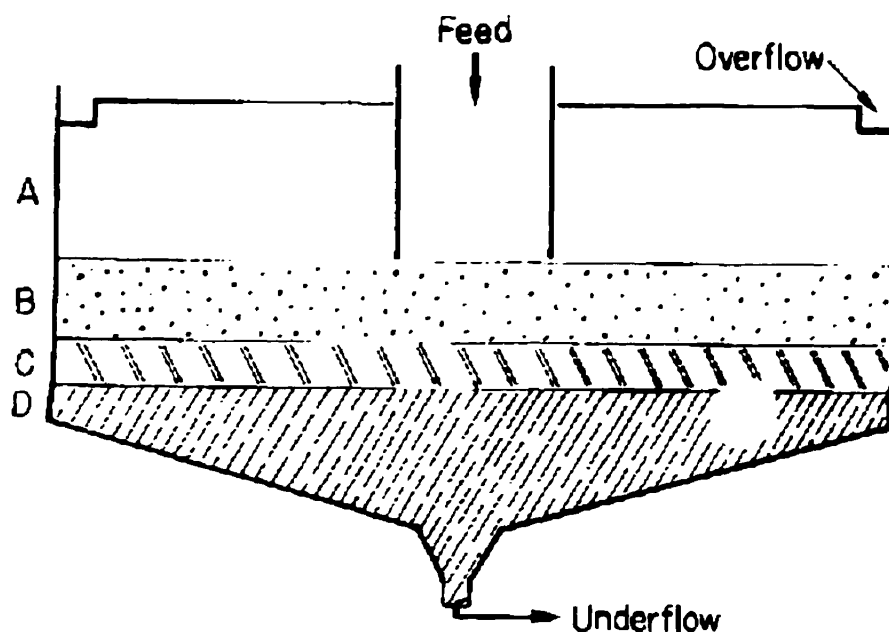


Figure 2.5: Four zones in a thickener: A) individual particle settling, B) flocculant settling, C) mass settling, D) compression settling.

Individual particle settling occurs at high feed dilution. Under this condition the particles are sufficiently dispersed not to interfere with each other. The zone in the thickener where individual settling occurs is called the clarification zone (zone A). With

increasing depth the settling velocity decreases since the number of particle-particle collisions increases. Particles whose settling velocity is less than that of the upflowing fluid will be carried out to the overflow.

Particles can agglomerate due to surface charge effects (coagulation) or due to addition of a flocculant (flocculation). In the beginning of the settling process they will settle according to agglomerate size. There is no sharp interface between subsiding pulp and the clear supernatant, but rather a progressive clarification as more small particles settle out (zone B).

At one point as the pulp becomes more concentrated, each particle or agglomerate or floc comes in contact with adjacent ones. In this case they link into a loose structure and are constrained to settle at the same rate. Fines are generally not left behind, causing a sharp interface between pulp and supernatant. This interface is called the sediment line and the settling is termed mass settling (zone C).

At higher depth the solids concentration increases even more and the pulp structure becomes firm enough to exhibit a plastic yield and develop compressive strength. Subsidence of any layer is then slowed by mechanical support propagating up from the bottom of the tank. The weight of the solids themselves acts as the compressive force to increase solids concentration by squeezing the liquid out. This zone is called the compression zone (zone D) and the interface between the sedimentation zone and the compression zone is called the mud-line or bed height.

## 2.4 Measuring interfaces

Problems can occur if the mud-line rises above a certain point causing some solids to exit with the overflow. Realizing the importance of level detection in thickeners, several

methods have been developed to measure bed height; however all of them have drawbacks.

Measurements based on turbidity [16, 17] give excellent results in predominantly clear liquids, but have a limited application in the systems encountered in mineral processing. One reason is they require frequent maintenance in processes (like thickening) where precipitate scales form on the detector.

Techniques based on ultrasonic absorption [18,19] are used extensively but are unreliable in many processing industries due to temperature limitations and instability often due to air entrainment or the effects of fluid currents.

More recently, natural radioactivity has been used to determine settled solid levels and solids concentration profiles [1]. The variation of solids density within the thickener was monitored using a gamma-ray gauge. Different mineral slurries have different levels of natural gamma-ray activity. Typical results from a red mud thickener are shown in Figure 2.6. This figure shows bed density profiles at several time intervals for a rising bed. The profile is influenced by the feed and underflow rates and especially flocculant addition rate. Identifying the top of the bed from the profiles is open to debate. The technique can be used on-line with a mobile single cell or a multi-detector stationary probe. Calibration is needed if % solids is to be estimated. However, the determination of the solids content is often difficult to achieve, since the radioactivity present in minerals and ores is generally low and these devices require time to accumulate sufficient counts for measurement purposes. The technique is expensive and subject to electrical noise which has been found to produce false readings or distort the results obtained.

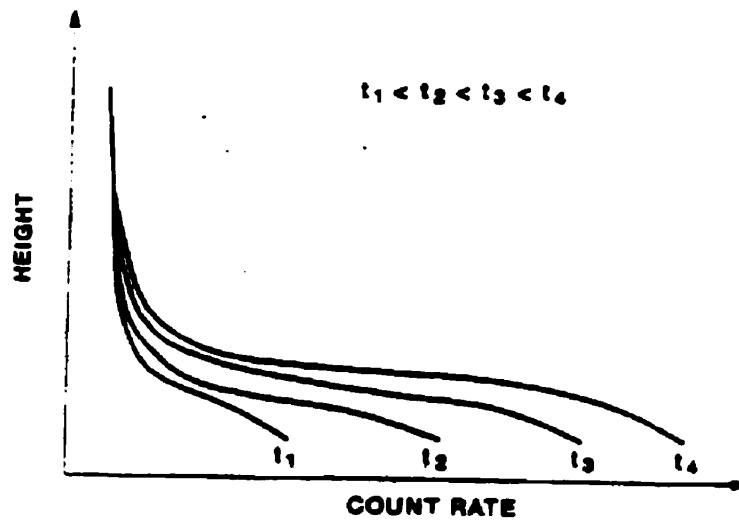


Figure 2.6: Consecutive profiles in a red mud thickener obtained with a gamma-ray gauge (taken from [1]).

Another technique uses an optical sensor [20]. Solids are sensed and the signal is transmitted via fiber optic cables to a remote location for decoding. The sensor uses modulated light beams (analog or digital). An optical laser sensor can be held stationary in a thickener at a critical depth. When the bed rises towards the sensor, the motion is detected by a drop in signal intensity and steps may be taken to decrease the bed. The major problem here is the time factor; by the time the rise in bed above the critical level is noticed it is often too late to make adjustments and loss of solids via the overflow can occur. To solve this problem a vertical array of optical sensors has been developed. However deposition on the optical transmitters can occur and frequent maintenance is necessary.

As mentioned in chapter 1, Williams et. al. [2-4] have made use of the dependence of slurry conductivity on the volume fraction of (non-conducting) particles to visualise the distribution of solids in a tank using electrical resistance tomography (ERT). By using several image planes (Figure 2.7), multiple slice views of the axial and radial distribution of



solids can be quantified. In the four isometric views shown in the figure, the concentration of solids in each pixel can be sensed. The method has been tested for low % solids (6 % v/v solids) and it is not known if the method works in thickeners of interest here with solids concentrations up to 75%.

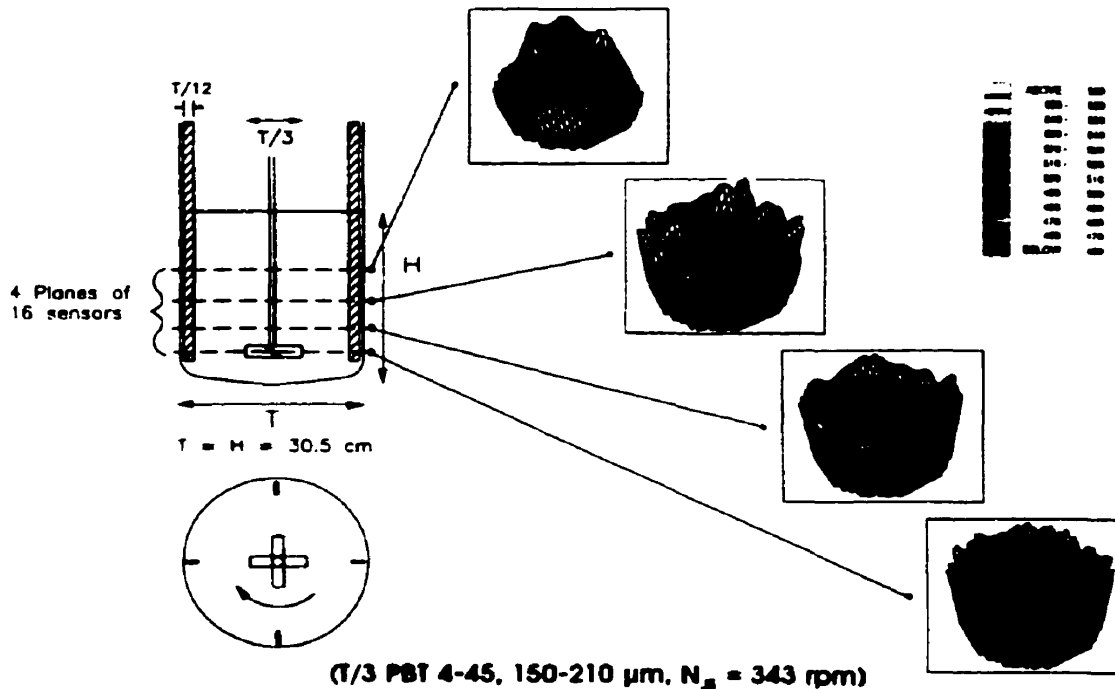


Figure 2.7: ERT imaging in a 30 dm<sup>3</sup> agitated tank using four equally-spaced planes of 16 electrodes. Isometric plots show corresponding resistivity profiles which can be converted into solid concentration profiles. Data for 6% v/v slurry of 150-210  $\mu\text{m}$  sand in water stirred with a six pitch-bladed impeller at 200 rpm [2].

Archer [21] used microwaves to detect the interface between pulp and froth in flotation cells, a technique that could be extended to thickeners. Experiments revealed that the froth caused extreme attenuation of the signal. The investigation of a system based on time-domain reflectometry, which uses baseband pulses to locate the interface, proved to

be more accurate.

When trials in the laboratory demonstrated the feasibility of this approach. Walsh [22] developed a pneumatic device to detect the position of the interface. The detector seeks a differential-pressure point that is generated by the difference between the density gradients either side of the interface. However this sensor is very sensitive to the fluctuating density of the froth and exploding or rapidly collapsing froth bubbles in flotation cells of large capacity triggered the pressure switch prematurely. Pressure techniques have been used in thickeners by Noranda.

The best way to monitor the solids concentration in a thickener would be to make use of a distinguishing characteristic of both solids and liquid that could be easily measured. One such characteristic is conductivity. Conductivity has been used in sensors for some time. Turner [23] monitored the electrical conductivity of beds of solid spheres (either ion-exchange resin, or non-sulphonated resin) fluidized by aqueous salt solutions. By varying the concentration of the solution, the ratio of the conductances of the two phases could be varied over a wide range to test Maxwell's model.

Gomez et. al [24, 25] and Uribe-Salas et. al. [26-28] applied a conductivity probe to detect the interface in flotation cells. In an extension of this the local concentration (holdup) of the gas phase was also measured by Tavera et. al [29]. Banisi et. al. [30] developed a technique for on-line simultaneous determination of gas and solids holdup, based on a combination of conductivity and pressure difference measurements.

The conductivity probe design previously developed for level detection in flotation machines was adapted to measure level and solids profiles in thickeners. The first design comprised 23 ring electrodes, a 24-channel relay, a conductivity meter and a computer [5,6]. A program written in Quick Basic was used to drive the data acquisition. Proof of concept

experiments were carried out in thickeners at Falconbridge's Strathcona mill (Ni concentrate and non-mag thickeners) and Kidd Creek Division (Cu, Zn concentrates and final tails in the concentrator and a jarosite thickener in the Zn plant) [5,6].

A custom designed conductivity probe was commissioned and installed in October 1994 at Copper Cliff, Ontario Division of Inco Ltd., operations [7-10]. This probe consisted of 31 electrode rings, two 16-relay boards, a conductivity meter and a computer. The design included a hinge to let the rake pass by (see chapter 3).

At the same time when the first experiments with the conductivity probe were being performed at Falconbridge, an Australian company ALOA Ltd. patented [31] a thickener "mud gauge" using a related principle. The apparatus, depicted in Figure 2.8, determines the concentration of solids and the interface between liquid and settled solids in a thickener using a capacity sensor (capacity is related to conductivity). The sensor (1) consists of a number of coils and is open in the middle to let slurry pass horizontally. It measures the capacity of the material within the generated electrical field. The sensor is in electrical communication with and suspended by a cable (2) from a winch (3). The winch is controlled by the operation of a motor (4) which is controlled by a monitoring device (5). The sensor signals are transferred from the cable to the sliprings (6) to a meter (7). The data are then passed from the meter to a monitoring device which measures the position from a shaft encoder (8) and controls the location of the sensor. The monitoring device is in electrical communication with the drive mechanism of the rake and is programmed to raise the sensor when the rake approaches and holds the output signal constant until the rake passes. The sensor is then repositioned at the last point of measurement and resumes recording data. When the sensor reaches the bottom of the thickener it returns to the surface.

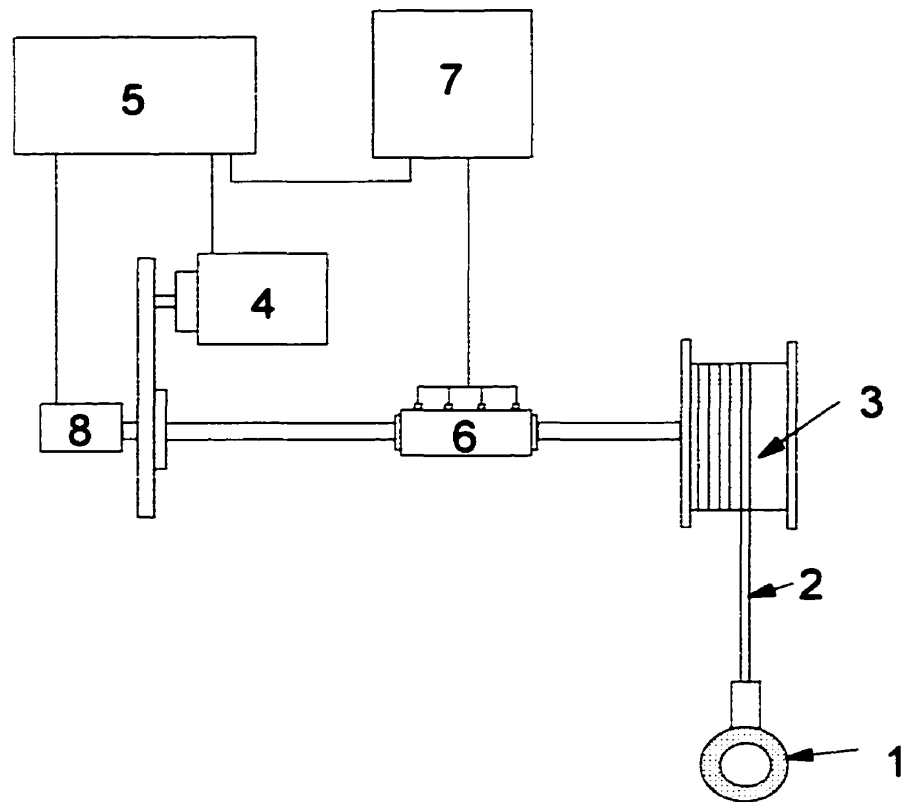
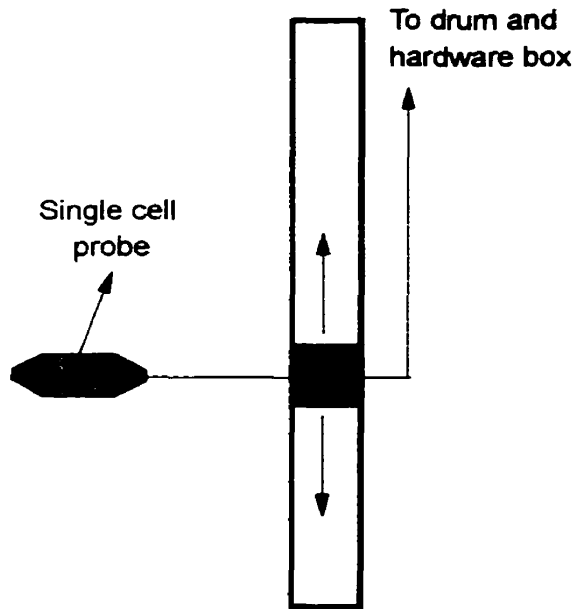


Figure 2.8: Schematic overview of the thickener mud gauge.

Some problems were encountered when the mud gauge was used in a concentrator thickener. As can be seen from Figure 2.8 the sensor (1) is open to let the slurry pass. If the slurry density is high there is a possibility the sensor will plug. A second problem is that the sensor has to be heavy enough to descend through a high concentration of solids. The mud gauge is also expensive. Another disadvantage is that, due to the movement of the probe, time has to be allowed for the system to stabilize before a measurement is taken. A perceived difficulty would be installation in an outdoor thickener in cold climates. The top of a thickener may freeze preventing the probe to from moving freely.

In 1997 Outokumpo made a patent application for a method based on conductivity to detect the mud level in a thickener [32]. The technique described in this patent is



similar to the single cell probe described in this thesis used to calibrate the stationary multicell probe (Figure 2.9). The disadvantages of this system are the same as mentioned for the mud gauge, except for the plugging. In the end the patent was rejected due to the similarities with the thickener mud gauge patent of ALCOA.

Figure 2.9: Mobile single cell probe developed by Outokumpu.

Below the principle theory of electrical conductivity is described.

## 2.5 Electrical conductivity

Electrical conductivity is the ability of a material to conduct electrical current. Electrical conductivity is an intensive property of a material, because it does not vary with the amount or shape of the material [23, 33, 34].

Ohm's law relates the current ( $I$ ) to the applied voltage ( $V$ ) as follows:

$$V = I * R \quad (2.1)$$

where  $R$  is the resistance of the material through which the current is passing.

Another expression of Ohm's law is:

$$J = \lambda * E \quad (2.2)$$

in which  $J$  is the current density (current per unit of specimen area,  $I/A$ ),  $\lambda$  is the electrical conductivity, and  $E$  is the electrical field intensity. Resistivity,  $\rho$ , is defined as the ratio of  $E$  and  $J$ :

$$\rho = \frac{E}{J} \quad (2.3)$$

The parameters  $E$  and  $J$  are often difficult to measure directly and therefore equation (2.3) is usually transformed to an equation with readily measurable quantities such as total current and potential difference.

The resistivity is independent of specimen geometry. If we know the resistivity of a material or solution, we should be able to calculate the resistance of the material of any length and cross-sectional area. If a potential difference  $V$  is applied across that substance, the electric field and current density will be constant for all the points between the two ends and will have the values:

$$E = \frac{V}{L} \quad ; \quad J = \frac{I}{A} \quad (2.4)$$

Substitution of equation (2.4) in equation (2.3) results in

$$\delta = \frac{E}{J} = \frac{V/L}{I/A} \quad (2.5)$$

where  $V/I$  is the resistance  $R$ . Therefore equation (2.5) can be written as:

$$\delta = \frac{RA}{l} \quad (2.6)$$

In equation (2.6)  $l$  expresses the distance between the points at which the voltage is measured and  $A$  is the cross sectional area perpendicular to the direction of the current. The electrical conductivity,  $\lambda$  in equation (2.2), is defined as the reciprocal of resistivity ( $\delta$ ):

$$\lambda = 1/\delta \quad (2.7)$$

### 2.5.1 Measurement of conductivity

Unlike metallic conductors, phenomena occur in an aqueous solution placed in an electric field which complicate the measurement of conductivity. Ions in solution are surrounded by a sphere of oppositely charged ions and water molecules. When an electrical field is imposed, the migration of the central ion deforms the cosphere of water and oppositely charged ions. This migration is called polarization, which tends to retard the transfer of free charges in solution, resulting in a reduced electrical current. For that reason, all standard devices that measure conductivity use an alternating current source, commonly with a frequency of 1 kHz.

The electrical conductivity of electrolytes is often measured by making use of a rectangular cell consisting of two electrodes (e.g. platinized platinum plates) covering the entire cross-sectional area of the cell (Figure 2.10).

Such a geometry is a section of an ideal cell consisting of two infinite and parallel plates where absolutely uniform potential and electrical current field exists [35]. Under these conditions, the conductivity of the electrolyte is related to the measured conductance,  $\Lambda$ , and the geometrical parameters of the cell by the well-known expression (equation 2.8):

$$\lambda = \Lambda \frac{A}{l} \quad (2.8)$$

where  $A/l$  is referred to as the cell constant.

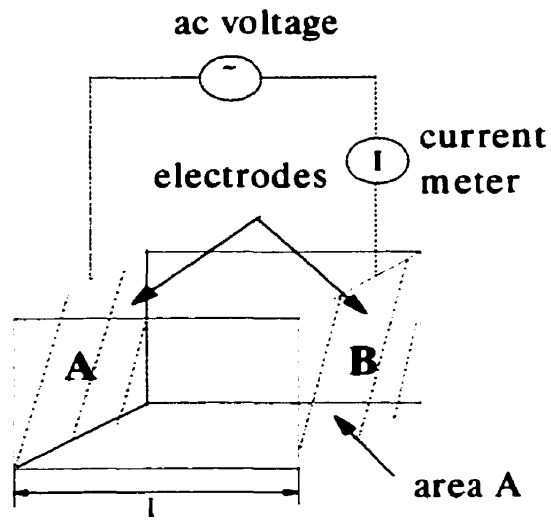


Figure 2.10: Conductivity cell and electric circuit to measure the conductivity of electrolytes.

A uniform field is also generated for two other cell geometries, two infinite and concentric cylindrical electrodes and two concentric spherical electrodes [35]. These geometries also allow the computation of electrical conductivity from geometrical parameters of the cell.

Obviously, these three cells are impractical for measuring the effective conductivity of dispersions. Nevertheless, it is desirable to try to conserve their basic geometry to provide conditions for uniform fields. Two “grid” electrodes covering the cross-sectional area of a settling column and separated by a distance represent an adaption of the cell consisting of two infinite and parallel plate electrodes and is, consequently, described by equation (2.8). The design also allows for the free movement of the phases. Such a cell was used by Achmal and Stepanek [36, 37], Turner [23], Dhanuka and Stepanek [38], Uribe-Salas et al. [24 -27], Shen and Finch [39], Banisi et. al. [30] to measure the effective conductivity of dispersions.



### 2.5.2 Electrical conductivity and solids holdup in two phase systems

Maxwell [33] appears to be the first to consider conductivity of dispersions. One system he examined was uniformly sized non conducting spheres in a sufficiently dilute dispersion where interactions between the spheres can be considered negligible. The effective conductivity of the dispersion  $\lambda_{1-d}$ , was given by:

$$\lambda_{1-d} = \lambda_l \frac{(1 - \epsilon_d)}{(1 + 0.5\epsilon_d)} \quad (2.9)$$

where  $\lambda_l$  is the conductivity of the liquid and  $\epsilon_d$  is the holdup of the dispersion (or solids holdup in the current situation).

Equation (2.9) can also be written as:

$$\epsilon_d = \frac{(1 - \Lambda)}{(1 + 0.5\Lambda)} \quad \Lambda = \frac{\lambda_{1-d}}{\lambda_l} \quad (2.10)$$

where  $\Lambda$  is the relative conductance and can also be expressed in terms of resistance:

$$\Lambda = \frac{\lambda_{1-d}}{\lambda_l} = \frac{R_l}{R_{1-d}} \quad (2.11)$$

and  $R_l$  is the resistance of the continuum (clear liquid) and  $R_{1-d}$  is the resistance of the dispersion.

Uribe-Salas et. al. [26-28] conducted experiments to measure solid holdups in two-phase systems (water-air and water-mineral) and found that Maxwell's model adequately described the experimental data. Yianatos et al. [40] found that the Maxwell model gave a good fit to measured gas holdups up to 30 % in a water-air (flotation) column with bubbles (<2 mm) stabilized by a frother. Tang and Fan [41] found that the model was suitable for particles <1.5 mm in a liquid-solid fluidized bed. Banisi et. al. [30, 34] and Tavera et. al. [29] found the model could be extended to measure gas holdup in gas-slurry dispersions by

treating the slurry as one, pseudo homogeneous, phase.

It should be noted that Maxwell's model, as in any model, is bound by certain limitations. The model assumes the particles are uniform sized non conductive spheres, and the solids holdup ( $\epsilon_d$ ) is low. In practice particles can be non spherical (but not platelets, Banisi et. al. [34]). Most solid particles in mineral processing act as non-conductors from experience.

### 2.5.3 Temperature effect on conductivity

The conductivity of electrolytic solutions varies with temperature, concentration and composition. As the temperature increases above 4°C, water has an expansion of 0.025 percent per °C in volume. This expansion should result in a small decrease in conductivity. Instead measurements show that the conductivity increases. Clearly, changes in volume do not account for the change in conductivity with temperature. Viscosity is the important factor. The viscosity of a liquid is affected by changes in temperature. The mobility of the ions will therefore be affected. The increase of conductivity of water by 2-3 percent per °C above 0°C appears to be related to the decrease of viscosity with temperature. The decreased viscosity reduces the resistance to the flow of ions, resulting in an increased conductivity.

An accurate determination of solution conductivity is achieved by performing measurements at a constant temperature. Usually a room temperature of 25°C is chosen as the standard. When the temperature of the sample changes, a correction has to be included to estimate the conductivity of the sample at 25°C. The actual sample temperature coefficient can be determined from either published data or from measurements on representative samples. This coefficient may then be applied to correct future measurements on samples of similar composition.

Once the temperature coefficient is known, the conductivity at 25°C can be determined from:

$$\Lambda_{25} = \frac{\Lambda_T}{1 + \alpha\Delta T} \quad (2.12)$$

where  $\Lambda_{25}$  = conductivity at 25°C.

$\Lambda_T$  = conductivity at measurement temperature T.

$\alpha$  = temperature coefficient of conductivity (change per degree C).

$\Delta T$  = difference between measured temperature and 25°C (T-25°C).

## 2.6 Theoretical conductivity profile in thickener

Based on the difference of conductivity between clear liquid and slurry the anticipated conductivity profile is shown in Figure 2.11.

We can see that the conductivity of clear liquid is higher than that of slurry. With increasing depth the solids concentration increases. Two transitions are seen. The first is identified with the sediment line when the sediment zone is reached (§ 2.4). The second locates the mud-line and the start of the compacted/compression zone.

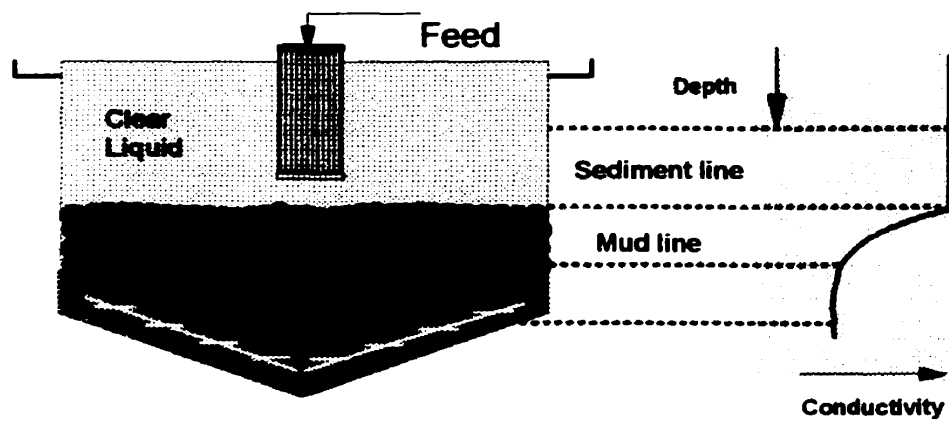


Figure 2.11: Expected conductivity vs. depth profile in a thickener.

With this background to thickeners and the conductivity technique, a closer look at the experimental setup is given in the next chapter.

# CHAPTER 3

## EXPERIMENTAL SETUP

In this chapter the portable (calibration) probe and the industrial probe are discussed, along with the data acquisition system and the original and newly developed software.

### 3.1 Industrial conductivity probe

The conductivity probe is installed in the concentrate thickener 1A of Copper Cliff, Ontario Division of Inco Ltd. at  $r/R = 0.6$ , or roughly half way between the centre and the edge of the thickener and is attached to the catwalk. The setup consists of a stainless support steel bar and the probe. The probe has 32 stainless steel rings, each 1.27 cm thick and spaced 10 cm apart by PVC (Figure 3.1). The rings are connected to two relays each so that they may be positive or negative to form a complete conductivity cell on either side of the positive ring.

The probe is filled with epoxy resin with rubber O rings around the metal rings to ensure no ingress of liquid. The diameter of the probe is 5 cm and the working length (length where rings are present) is 3.3 m. A pivoting system allows passage of the rake (Figure 3.2). There are two rakes moving at a speed of  $8.8 \text{ rev h}^{-1}$  [42].

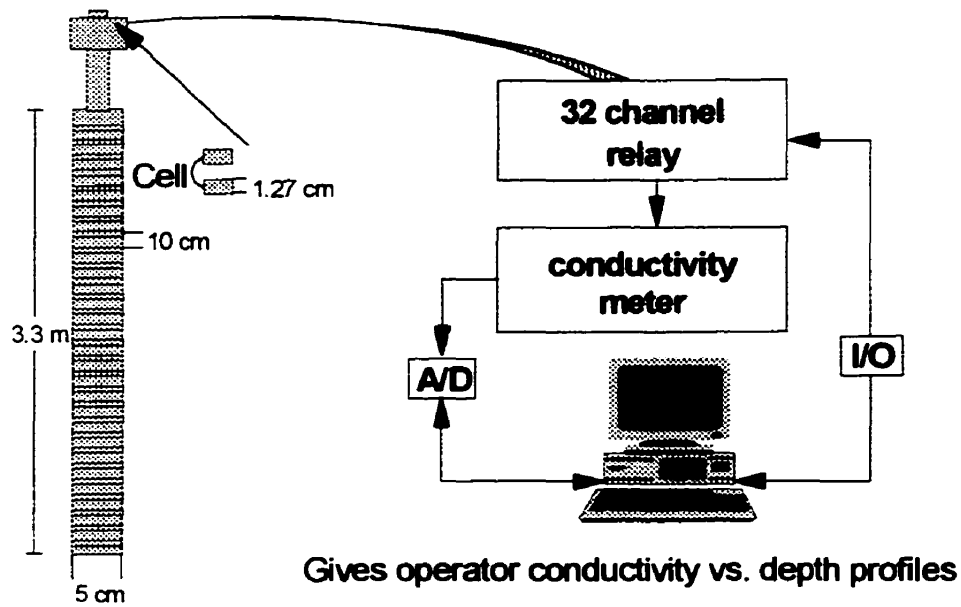


Figure 3.1: Conductivity probe and data acquisition.

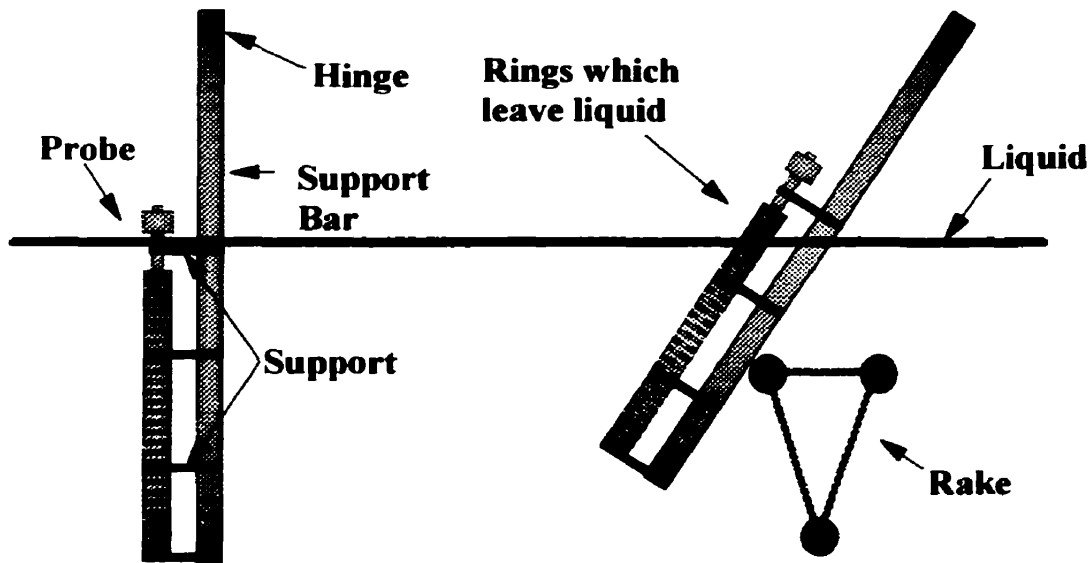


Figure 3.2: Probe design and movement during passing of rake.

The probe is sufficiently heavy to return to its original position after the rake passes. However, when the bed in the thickener is very compact the probe can become stuck at an

angle of up to 10 degrees from the vertical. To help resolve this problem a rubber spring has been attached to the probe. The spring assists the probe to return after the rake passes. Figure 3.3 shows clearly the difference this spring makes.

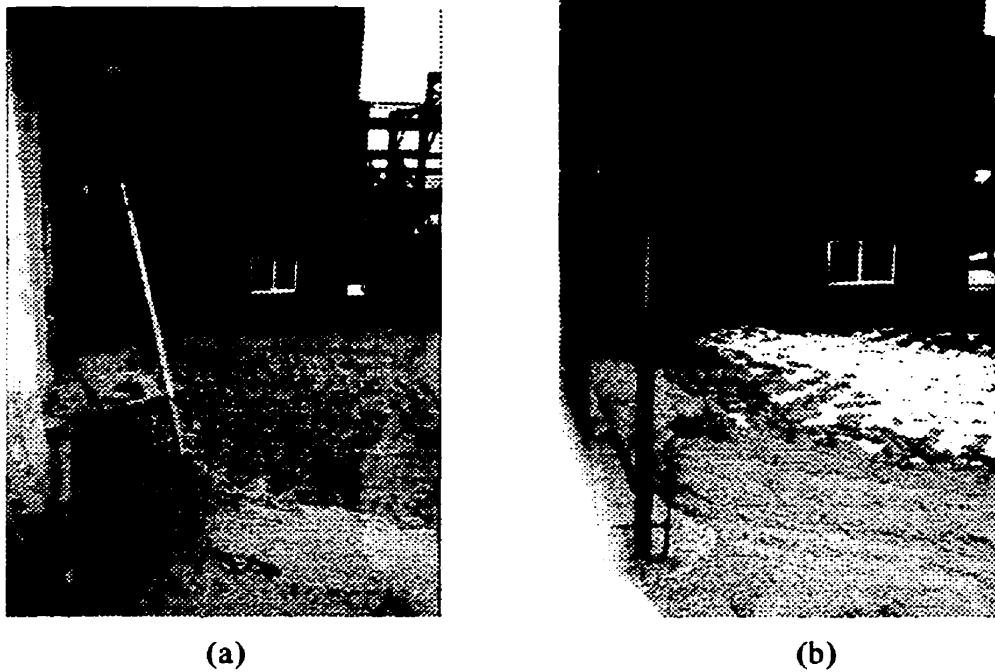


Figure 3.3: Before (a) and after (b) installation of rubber spring.

### 3.1.1 Data acquisition

At the top of the probe is a stainless steel connector box with an anphanol connector for a 32 pin cable. The cable goes to two relay boards. A PIO-12 card is used to control the relay board which has 16 relays. A computer with a program specially designed to drive the data acquisition is used and an A/D converter (DAS-8 card) of the AO variety is used to transmit signals to the plant computer system.

### 3.1.2 Maintenance of industrial probe

From past experience it was known that deposition occurs on the rings of the stationary probe. Deposition occurs continuously and can be countered by calibrating the probe (see chapter 4). By lifting the probe out of the liquid a couple of times a year to inspect the deposition it was found that the largest amount occurs in the spring and fall. Therefore it is recommended that cleaning should be done two to three times a year in those seasons.

The deposition is not uniform. The first two rings have a high oily (organic) coating coming mainly from the froth layer in this particular thickener. The next three rings also show oily residue (deposits were analysed using infra red which detected organic components). The next approximately 17 rings had mainly oxidized metal deposits. The last 10 rings had no deposition as these rings are mainly in the solids bed and subject to abrasion. The last ring even displayed some wear due to the abrasive environment.

Cleaning is done by lifting the probe into the horizontal position out of the thickener. A rope is connected to the bottom of the probe and, by pulling the rope (to the left or the right), the probe turns 90 degrees (the pivoting system supports this movement). The probe is pulled out of the water and placed horizontally next to the catwalk and cleaning can begin. By using sandpaper the deposition is removed from the rings. After cleaning, the probe is slowly lowered back into the thickener. Special care has to be taken that the rake does not come by at that moment since the probe and the rake can be damaged.

### 3.2 Portable probe

Ingham [43] designed a hand held single cell probe to calibrate electrode rings in a flotation column. The same probe was used to calibrate the industrial probe.



The portable probe, shown in Figure 3.4, consists of three internal stainless steel rings of 9 mm wide, each one separated by 6 cm. These electrodes are mounted flush on the inside wall of PVC tubing. The sensor is 3.81 cm in diameter and 24 cm in height. The wiring is concealed within the walls. To penetrate a compacted solids bed a stainless steel cylindrical section was added at the bottom of the probe. A piece of PVC tubing separates this stainless steel section from the bottom ring, so it does not affect conductance measurements.

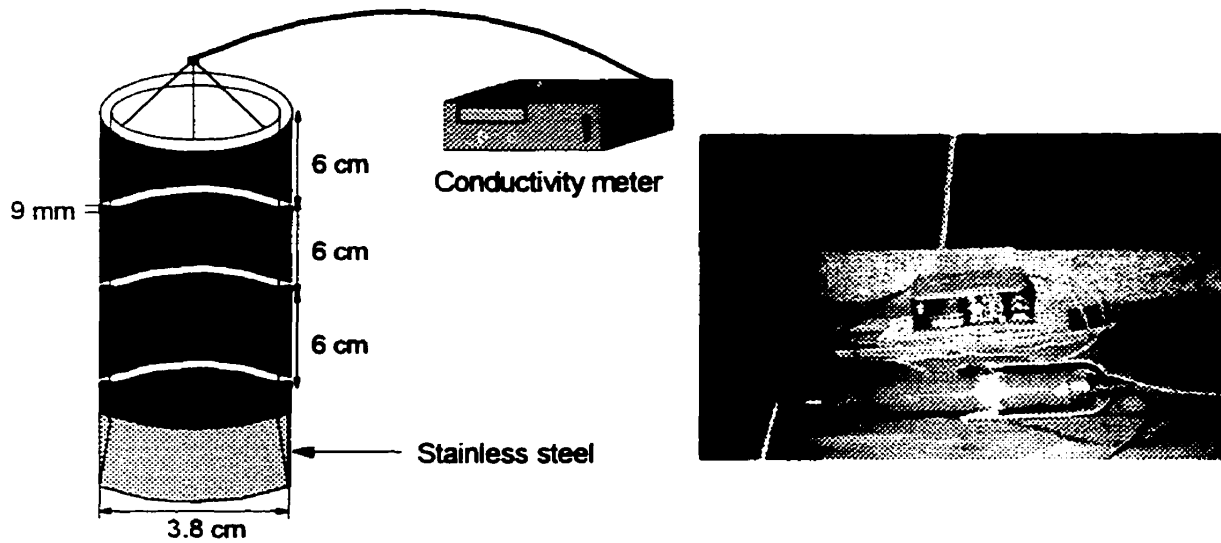


Figure 3.4: (a) schematic of the portable probe; (b) portable probe and conductivity meter.

The rings are connected to a conductivity meter, such that the top and bottom rings are negatively charged, and the middle is positive (Figure 3.5).

The internal ring design of the portable probe is in contrast with the industrial probe which has the rings mounted on the outside. Electrical currents produced with the external ring design have no boundary limits and therefore can interact with the objects in the vicinity (This is not an issue in most thickeners as they are very large compared to volume occupied by the electrical field). The rings of the portable probe constrain the electrical field within

the cell, thus reducing outside effects (see Figure 3.5).

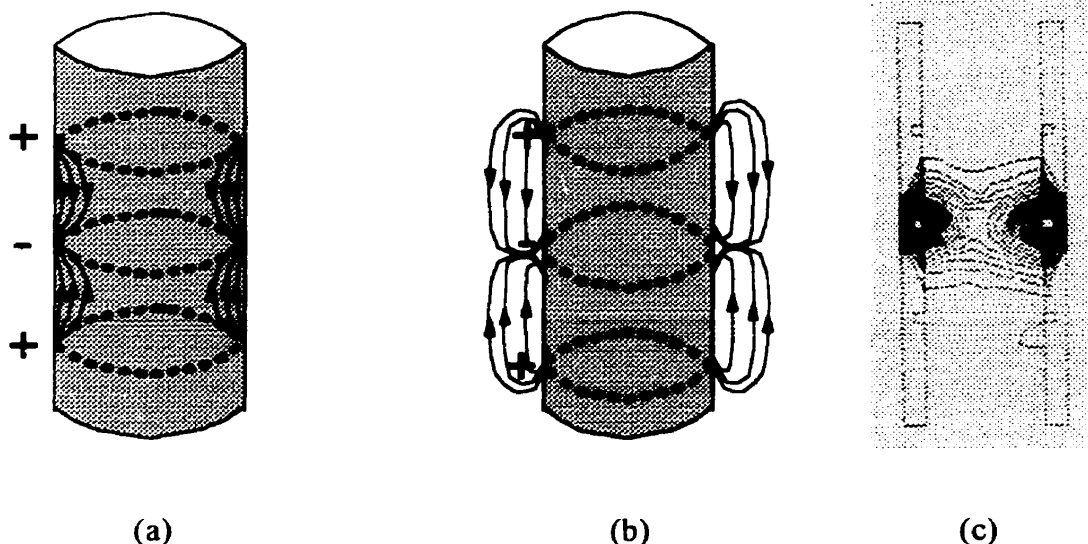


Figure 3.5: Electrical field of portable probe (a), industrial probe (b) and a computer generated (using MagNet 5.1) view of the equipotential lines of portable probe (taken from [44]) (c).

A favourable characteristic is that the hand held probe is free from the effects of deposition which is readily removed anyway. The hand held probe is used to eliminate differences in readings of the industrial probe resulting from the uneven deposition, i.e. to calibrate the industrial probe.

The portable probe needs initial calibration to convert conductance to conductivity. The procedure is carried out by lowering the portable probe into a vessel with liquid of known conductivity. The conductance is plotted against the conductivity (changed by adding KCl). Linear regression gives an equation to convert conductance to the required conductivity (Figure 3.6).

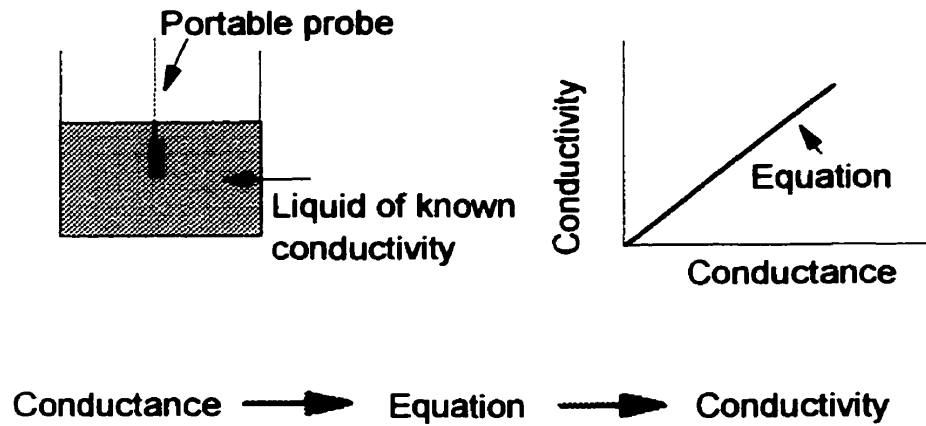


Figure 3.6: Calibration of portable probe.

### 3.3 Software

Originally the probe was driven by a program written in Quick Basic. A new program was developed in Visual Basic to create a more user friendly interface. To understand the data collection both programs are discussed below.

#### 3.3.1 Quick Basic

The original software was written in Quick Basic, since the subroutines accompanying the DAS-8 card were in Quick Basic. The first software designs were for research purposes for other projects which used conductivity [39]. For example, an automated technique to measure settling velocities of slurries used similar software [45]. Probst [10] modified this program to read % solids in a thickener.

The software includes day and week histograms (Appendix A, section A). The top right of the screen shows the current profile of depth against % solids; the bottom has a histogram which displays the inventory and the “interface” (a customized output) over the last seven days with the current day magnified; the top left of the screen has the current

reading, the day average and the week average of the load and level of solids. The screen is designed in a way to make it possible to view without interfering with data acquisition.

To compensate for problems like power failure, the program restarts automatically. The program starts without prompts so anyone can run it. The complete program is given in Appendix A. File naming and saving is automatic; every seven minutes a reading is completed and readings (conductivity) from the 31 cells are saved. File names are based on the date and a two letter code, e.g. IN0501.dat means INCO file of May 1, which contains all the data stored on May 1<sup>st</sup>. The file is also closed daily and can be retrieved at any future time for processing. There is one problem with this kind of file saving: there is no year included. After one year the data collected on May 1<sup>st</sup> will overwrite the data collected on that day a year before. This saving sequence can be seen in Appendix A, section B. The data has to be retrieved from the files and saved on diskettes before the end of the year, otherwise they are lost. A positive, however, is that this program will not suffer from the "Millennium Bug", since it is not depended on the year.

In each data acquisition event there is an averaging to reduce hardware noise. To stabilize the signal 25 data points are averaged over a fraction of a second: this can be seen in section C of the program.

The plots are designed to ignore defective rings. A large jump in a profile caused by a malfunctioning ring could be misinterpreted. For this reason a series of error codes have been included in the software which enables the operator to clearly define the problem. For example from section D from Appendix A, 4095 means a short-circuit. When ring 12 has short circuited there appears the message "Error; 12 4095" on screen. Defective rings increase the standard deviation from the reference ring (ring 5) thereby causing deviations in the estimate of % solids (see chapter 4: calibration).

When the probe is pushed aside by the rake the top rings emerge from the froth and the top bottom rings from the bed. Since this will cause errors in the program (and confusion for the operators) the program includes a routine to wait for the rake to pass by monitoring the top cell before taking another profile. After the rake has passed two minutes are given to let the inventory stabilize before data acquisition proceeds.

The maximum load is defined as 2500E+3 kg, expressed in this program as 2500 tonnes in section E, since the operators work with tonnes. When the load is higher than 2500, the program will give a 4095 code, which means error the load is above its limit. The maximum load can be changed by altering changing the number. Caution has to be taken to change all the 2500 numbers in the code.

In section F of the program, we can see how the digital signal (d%), collected when two activated electrodes are connected to form a cell, is transformed to conductance:

$$K = d\%^3 * 6.0636E-11 + d\%^2 * 8.42806E-8 + d\% * 0.012095 - 9.675 \quad (3.1)$$

The conductance the probe measures has to be corrected for the resistance of the length of tube which connects the probe to the conductivity meter. Therefore conductance is turned into resistance by:

$$K=1000/K \quad (3.2)$$

In equation 3.3 the resistance of the tube is subtracted:

$$K=K-3.927 \quad (3.3)$$

The K becomes conductance again by:

$$K=1000/K \quad (3.4)$$

The (standardization) cell constants (for calculation see chapter 4: calibration) for the probe are given in section G. The user has to update those cell constants herself, which means she has to change the values in the program. This process has been found rather difficult to fulfill in operations and was one of the reasons to change the program to VB.

### 3.3.2 Visual Basic

In the modification of the Quick Basic (QB) program, Visual Basic (VB) version 3 was used to make the operator/software interface more accessible. The main part of the program is the first form that pops up when the application is started (called Initial.form). Here the general parameters are defined and the program is loaded. The largest difference with the Quick Basic program are the interfaces which are made with in-line graphic controls provided by VB automatically. Also the VB library (VTX) takes the parameter by moving the mouse over the form instead of specifying it by commands like LINE, LOCATE and PRINT (see Appendix A) in QB. This makes implementation much easier.

In VB all event handlers are written in separate subroutines in a special order of events which is accompanied by structures and modules defined by the programmer. The flow chart of the program is given in Figure 3.7, where the most important parts of the Visual Basic program are given.

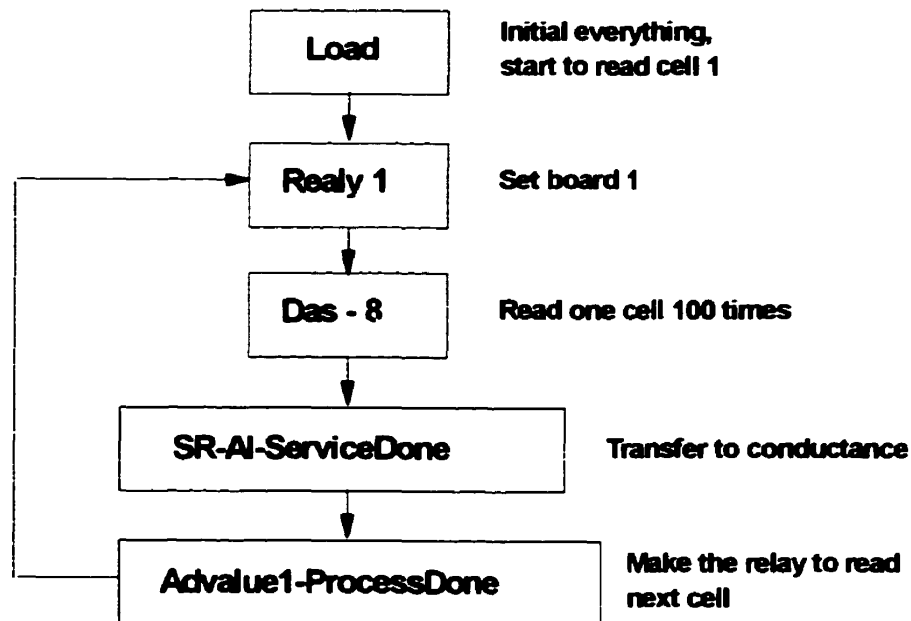


Figure 3.7: Flowchart of Visual Basic program for first 16 rings.

Reading a cell of the probe is controlled by the relay board. To control which bits on the relays have to be closed and which opened to read the required cell, the cells are numbered. There are two relay-16 boards, named board a and b in the program. The program starts with board a and each bit has a number. The number builds up as  $2^n$ , with  $n = 0 \dots 15$ . The result can be seen in Figure 3.8. It shows that when two bits are connected to form one cell, the cell can be defined by the addition of the individual bit numbers involved. For example cell 1 is  $2^0 + 2^1 = 3$ , cell 2 is  $2^1 + 2^2 = 6$ , etc. Unfortunately it is not possible to read cell 16, since it is not possible to connect two boards at the same time [46]. When going to board b, first board a has to be closed and then board b has to be opened and the cell reading is identical to board a.

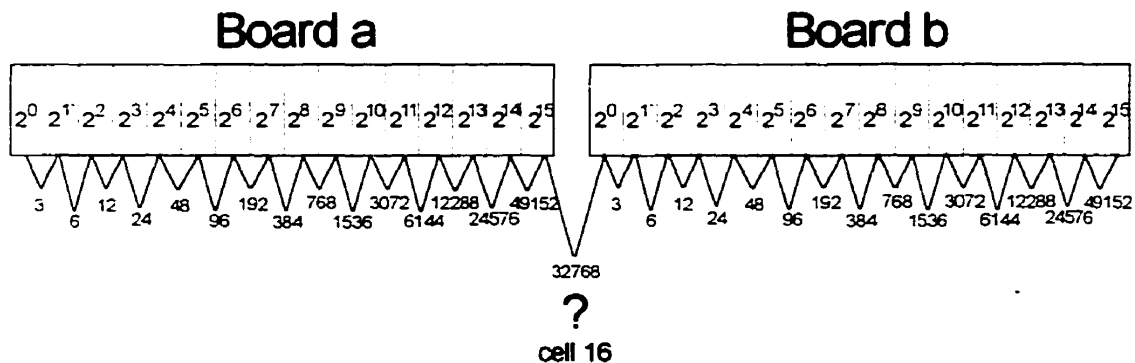


Figure 3.8: Two relay-16 boards with bits and numbers.

In Appendix B the main parts of the Visual Basic program are given. The first three subroutines handle the data reading of board a, in the last subroutine of these three (rel1\_ProcessDone), DAS-8 was called. The subroutine DAS-8 is an important subroutine that controls the DAS-8 board, which is followed by subroutine SR\_AI\_ServiceDone that handles the voltage coming from the DAS 8 to convert it to conductance.

From the program it can be seen that there is a difference with Quick Basic. In QB the signal is digital not a voltage. In Visual Basic it is volts. There has to be a new equation established to convert this voltage to conductance. This is done on-site by attaching a

resistor between the relay and the conductivity meter (Figure 3.8).

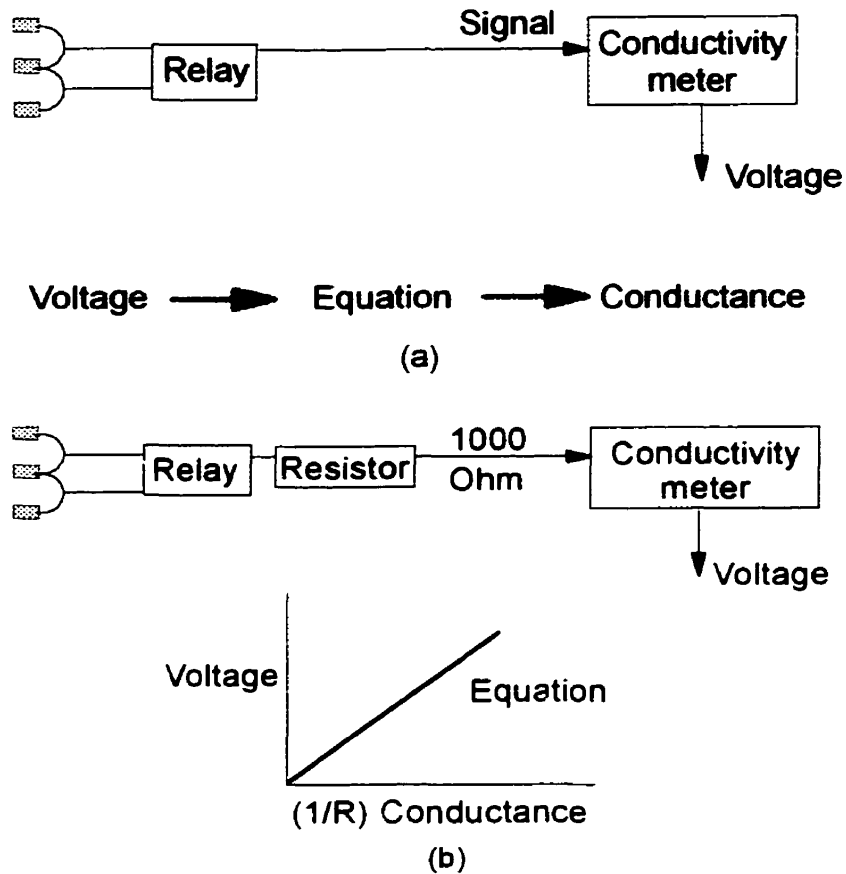


Figure 3.8: (a) collection of signal from probe and transformation to voltage using conductivity meter; (b) transforming voltage to conductance.

The resistance is varied and each time the voltage is measured from which, a conductance vs. voltage calibration is created (Figure 3.8 (a)). Linear regression gives an equation which transforms all voltage to the corresponding conductance (Figure 3.8 (b)). Unfortunately this is the only part of the Visual Basic program which has not been completed, due to lack of time. All other parts of the program has been tested, debugged and verified.



### 3.3.3 Data retrieval

Most data have been collected with the Quick Basic program, since the Visual Basic is still in the development stage. Earlier it was mentioned that the data files can be collected from the plant computer, in this section this data retrieval is outlined. It can be either done at the computer itself or remotely, since the computer in the plant has a DAS-8 card of a type which enables the computer to send and receive signals. If the remote computer also has 2 relay-16 boards and a DAS-8 card of the same type even changes to the program are possible and can be sent to the plant computer. It is also possible to see directly what the screen of the plant computer is displaying. To collect data files from the plant computer remotely the procedure below has to be followed. If the data files are collected directly from the plant computer the PC Anywhere steps can be ignored (PC Anywhere is a software which links two computers together when both have PC Anywhere).

#### *Procedure to collect data from plant computer*

- Start PC Anywhere.
- Go to **Call a Host PC**.

Enter the phone number to connect to the plant computer: (705) 682-8709 (when using a remote computer that is already on Copper Cliff, Ontario Division of Inco Ltd. property only 8709 has to be entered). In PC Anywhere it is possible to set-up a frequently dialled phone number beforehand. After setting it up the user only needs to select it each time he want to use that particular phone number and hit enter. The phone number is dialled automatically.

- Depth vs. % solids profile of the plant computer is now visible on screen.
- Press F1 or CTRL X to exit the program
- Change directory to INCO by entering `c:\cd..` followed by `c:\cd INCO`.
- Enter "dir" (`c:\INCO\dir`) and a list of files pops up, all having the structure IN + month + day, like IN0501.dat referring to May 1 as was seen earlier in §3.3.
- When the user is at the plant computer the desired files can be copied directly to a

diskette.

By reducing the space the files take it is better to zip the data files. Use the following procedure to retrieve the data files from plant computer when on-site:

C:\INCO\cd..

C:\A:

A:\mkdir Month.zip, for example May.zip

A:\C:

C:\cd INCO

C:\INCO copy IN05\*.\* A:\May.zip, this command copies all May files to directory May.zip on diskettes A.

C:\INCO del IN05\*.\*, this command deletes all May files on the harddisk and creates thus more free harddisk space.

- When using a remote computer with PC Anywhere (AW) type “AWsend” from directory INCO.
- Press **Ctrl Enter** to select files that are to be sent to the remote computer.
- Select **Disconnect when done** from the PC Anywhere menu.
- Click **Send** and the files are transferred to the remote computer and PC Anywhere will terminate the connection.

The data which is collected has to be converted to useful outputs. This will be discussed in the next chapter after which one such measure, bed height or level, is discussed.

# CHAPTER 4

## CALIBRATION OF STATIONARY PROBE

To process the data from the conductivity probe, one has to first check the data's integrity. In chapter 3 it was mentioned that deposition on the rings can occur, therefore calibration is necessary. Several possible ways to calibrate the probe have been investigated and each of them will be described below, with their advantages and disadvantages. Two methods will be discussed more extensively. Also the frequency of calibration will be investigated.

### **4.1 Standardisation method**

#### **4.1.1 Description**

The standardisation method involves the use of relative cell constants as corrective measures to make sure all the rings would read the same value if placed in a conductively homogeneous solution. The key to this procedure is ensuring that the rings are in the same solution. The first step in the procedure is determining which rings should be reading the same value. This is the most crucial step and has to be done with great care. Normally, there

are several rings which are always surrounded by clear liquid. Assuming that temperature effects are minimal (normally the case) and that the solution is homogeneous, all of these rings can be adjusted by choosing a reference ring and calculating the ratio of the conductivities over a period of time. The compacted solids at the bottom yield another zone which has several rings of equal conductivity. The difficulty therefore lies with the rings between the clear liquid and compacted solids (sedimented zone). To calibrate these rings an assumption must be made. On a graph of depth vs. % solids, there are two linear regions (liquid and compacted solids) which are roughly parallel but offset (by the compacted solids density). Assuming that it is not possible to have a more dense region resting on a less dense region, the interfacial rings must represent a smooth transition from liquid to compacted solids. In practice, few points have to be calibrated this way as at different times in the day rings will be in the liquid or compacted solids so that they can be calibrated by reference to these zones.

#### 4.1.2 Methodology

The first step is to collect data from the probe computer (this procedure was described in § 3.3 data retrieval). When the data have been collected they need to be processed using spreadsheet software such as Quattro Pro, Excel or Lotus 1-2-3. It does not matter which spreadsheet is used, the only condition is it must have facility for linear regression. The data read as a text file. If the data have been correctly imported the date should be at the top left, followed by rows and columns of data. The extreme left column has the time of the reading, the next 31 columns have the readings of the 31 cells from top to bottom, the 33<sup>rd</sup> column has the “sediment line” reading (point of greatest change in the profile), the 34<sup>th</sup> column has the “mud line” (where the curve goes vertical again), the 35<sup>th</sup> column has the load in short tons and the 36<sup>th</sup> column has the interface calculation (chapter 5).

The following spreadsheet in Quattro Pro software has been used for data processing.

**Sheet 1:** Raw conductivity data

**Sheet 2:** "Standardised" Conductivity

raw conductivity data / relative cell constant

**Sheet 3:** Solids by weight

$$\{(SD) * (SV(x))\} / \{1 + (SD - LD) * (SV(x))\} \Rightarrow$$

$$\{4.2 * (SV(x))\} / \{1 + 3.2 * (SV(x))\} \quad (4.1)$$

SV(x) = volume percentage of solids cm<sup>3</sup>

SD = specific gravity of the solids = 4.2 g/cm<sup>3</sup>

LD = specific gravity of the liquid = 1.0 g/cm<sup>3</sup>

**Sheet 4:** Corrected solids. In Figure 4.1 a typical depth vs. % solids w/w is depicted. As can be seen the % solids in the froth and throughout the liquid zone is not zero. This sheet is made to correct this. Below the procedure to accomplish this is discussed.

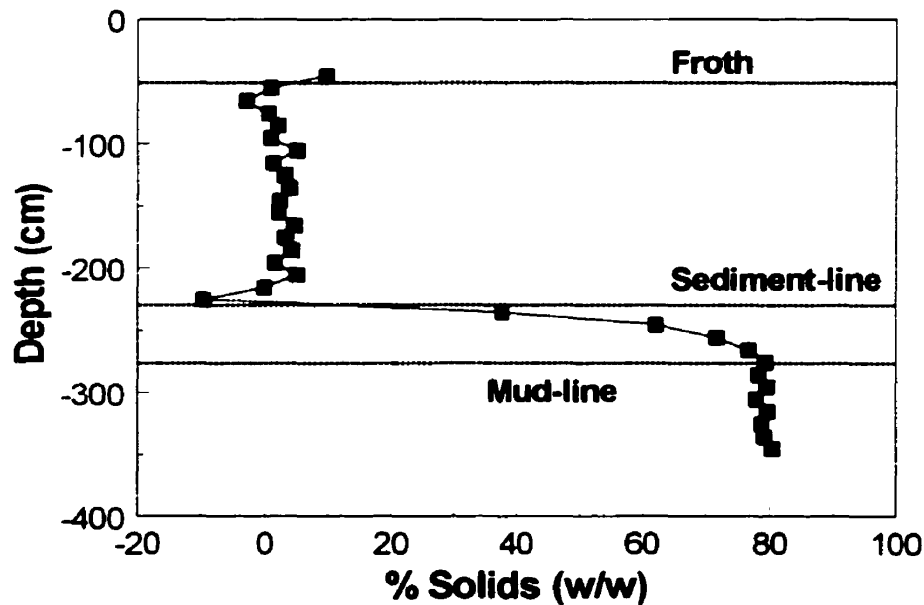


Figure 4.1: Depth vs. % solids by weight.

The froth should be neglected and therefore all % solids values associated with the froth are set to zero, also liquid should have zero % solids. This is accomplished by the following:

IF % solids < 0

OR IF % solids reading of a cell > minimum % solids readings after that cell

AND % solids < 10 %

THEN % solids = 0 (This % solids is called the corrected % solids = corsolids)

**Sheet 5: Solids by volume**

$$\{1 - \text{cond}(\text{ring}) / (\text{condav}(\text{ring}))\} / \{1 + 0.5 \times \text{cond}(\text{ring}) / \text{condav}(\text{ring})\} \quad (4.2)$$

$$\text{with } \text{condav}(\text{ring}) = \{\text{cond}(\text{ring}) + \text{cond}(\text{ring}+1) + \text{cond}(\text{ring}+2)\} / 3$$

**Sheet 6:** Since materials settle in layers in a thickener tank, each layer may resemble a ring or a horizontal slice through the cylinder. Equation (4.3) may be used to calculate the volume of a given ring of material:

$$V(x) = \pi \frac{D^2}{4} h \quad (4.3)$$

where  $h$  = interval between measurements, which corresponds with the thickness of the ring

$D$  = diameter of the thickener where the measurement is performed.

Load is the sum of the dry solids in the tank:

$$\{V(x) * (S(x))/100 * SG\} / \{SG - (SG - LD) * (S(x))/100\} \Rightarrow \{88.289 * (S(x)/100 * 4.2) / 4.2 - (3.2 * S(x)/100)\} \quad (4.4)$$

$V(x)$  = volume of a ring at a given depth  $x$  = 88.289 cm<sup>3</sup>.

$S(x)$  = mass percentage of solids.

$SD$  = specific gravity of the solids = 4.2 g/cm<sup>3</sup>.

$LD$  = specific gravity of the liquid = 1.0 g/cm<sup>3</sup>.

The total load can be calculated as follows:

$$Load = \sum_{x=1-31} V(x) * S(x) * \frac{SG - LD}{SG - [S(x) * (SG - LD)]} \Rightarrow$$

$$Load = \sum_{x=1-31} V(x) * S(x) * \frac{3.2}{4.2 - [S(x) * (3.2)]} \quad (4.5)$$

Also the load in the cone has to be taken into account. This is done by adding the volume of the cone:

$$V_2(x) = \frac{\pi}{3} r^2 H$$

where  $r$  = radius of the thickener where the measurement is performed.

$H$  = height of the cone

For standardisation, regression is used. A reference has been selected, which remains in the liquid. For each cell linear regression is performed on the raw conductivity data, using the following procedure (in Quattro Pro).

Select: Tools => Advanced math => Regression

A window will appear which contains:

*Independent:* Data: put the range of the column (e.g. B4 ...B..)

*Dependent:* Data F4...F.. (fill in range of column F, this is the reference)

*Output:* Put the range of the output (e.g. B (bottom of column) ...D (bottom of column))

*Y intercept:* Zero

Press OK

The result of the linear regression is shown in the output. The  $R^2$  value can sometimes be negative, this corresponds to a moving bed or the probe being stuck. The x-

coefficient corresponds to the relative cell constant. A comparison can be made with the preceding cell constant and usually they are not very different from each other for cells in the liquid.

A different approach is applied to calculate the relative cell constant of the solids. The underflow density of the thickener has to be known. The U/F is usually between 75-80 % solids. To have the most up to date data the Booster station of Coppercliff was called to obtain the U/F density. The datum of each cell that is in the solids is divided by a relative cell constant to obtain a % solids close to the U/F density. However, as of recent the operators no longer have the U/F data available anymore, which makes it more difficult to standardise the cells in the solids. An indication of the U/F density can be obtained by observing the flocculant rate vs. torque data (chapter 6).

The interface is the most difficult zone to calibrate. The zone is now divided into two sections; one containing more liquid (SLinterface) the other more solids (SSinterface). To see which rings are in the SLinterface the conductance data have to be inspected. When the values of the data are more in range of conductance of liquid, we are in the SLinterface; if the conductance resembles more the solids region, we are in the SSinterface. To calculate the cell constants for the SLinterface at least 80 adjacent points have to be chosen that have conductance based on liquid. A linear regression is done over these 80 points giving a new cell constant. For the SSinterface at least 80 adjacent points have to be chosen that have conductance based on solids.

After all the relative cell constants have been updated they can be transferred to the QBASIC program. To enter this program, connect with PCAnywhere to the probe when plot of depth vs. % solids is seen press F1. The DOS prompt will appear. Change directory to QB and type QB (C:\QB\QB). After the statement DATA (section E, Appendix A)



change numbers into the new constants. During this update the probe does not record any measurements since the program is offline. After all the constants have been updated and saved QBASIC has to be exited and the computer restarted. The depth vs. % solids profile is seen again and has to be inspected to determine if all the spikes (deviations) are gone. If this is not the case the ring which is generating a spike has to be calibrated again (usually this applies to rings in the SS or LS region).

This linear regression method has advantages and disadvantages:

*Disadvantages:* This method is not a real calibration method, data being compared to what they should be from theory and from the trend in the data over the year. Also the method is quite complicated, since the operator must have some understanding of spreadsheet programs and interpretate the profile so she/he can recognize the interface levels.

*Advantages:* The method is quick and gives quite accurate results and can be done at any moment when thickener is operating normally.

## **4.2 Curve fitting**

### **4.2.1 Description**

Curve fitting is the process of fitting a curve to collected data from a portable single cell probe (see § 4.4 portable probe calibration) and using the equation to adjust the relative cell constants so that the readings of the multicell (industrial or stationary) probe fall on the curve.

### **4.2.2 Methodology**

The data are collected and manipulated as in section 4.1, except that a curve fitting software must be chosen (Excel, Quattro Pro, Jandel Scientific). Once data has been collected the profile should be examined to make sure that it is smooth and then a model

should be obtained. Using the same equation a new set of coefficients should be calculated for a profile several hours later and this should be compared with the actual data. If there is good agreement, the model is sufficient and can be used to determine relative cell constants.

The advantages and disadvantages of the curve fitting method are:

*Disadvantages:* This method needs another method (portable probe) to succeed. Also the feed characteristics must have little variation over time and the model that is chosen should not be modified too often as it may not be representing the actual condition of the thickener.

*Advantages:* This method does not require all the rings to obtain a profile for curve fitting and it is not difficult to carry out.

## 4.3 Individual ring profiling

### 4.3.1 Description

The conductivity probe is on a pivot support system so that it can be pushed out of the way by the rakes (chapter 3). This means every time the rakes come by rings are moved from their normal depth to a shallower one. For calibration purposes this means several things. First of all, there are several rings which will be moved out of the sediment zone and into the clear liquid zone. With a reading in the clear liquid the ring can be calibrated with respect to the reference ring in clear liquid. Rings which do not rise out of the solids at least change their location. The reading at a higher level can be compared to the reading normally taken at that depth and since that ring can be calibrated *visa versa* the liquid ring when it rises into the liquid a two step calibration can be performed. For example, a ring just below the sediment line moves up and reads a value 10% higher than the reference ring. The relative cell constant for this ring is therefore 0.9 or a 10 % reduction to make it read the same as in the liquid. If a ring at a lower level reads 10% higher than this ring when elevated to the same depth, its cell constant would be  $0.9 * 0.9 = 0.81$ . In this manner, all rings can

be recalibrated as they are moving to different heights. This neatly takes advantage of the motion of the probe.

### 4.3.2 Methodology

The program in Appendix A used for data collection does not collect data when the rake goes by, therefore another program in QB was made to allow the probe to continue to collect data during passage of the rake. This program saves one file for each ring. When the speed of the rake and the angle of the pivot is known, the ring profiles - particularly those in the solids - can be used to map the bed. For example, if the bottom ring is rising at a known velocity and taking readings on the way up, it gives a solids profile. This profile can be compared to the ones taken from the probe's stationary readings and used as a diagnostic.

Although this seems a useful method it was not pursued, since there are too many disadvantages.

*Disadvantages:* If the probe gets stuck in the froth or the ice during winter, its velocity through the bed slows down and could cause incorrect calibration. Another problem is that when a ring moves upward it does not necessarily come to the exact position as a ring which was there when the probe was stationary, causing incorrect calibration. Also each ring contains different amount of deposition (or even none), which makes comparison between rings more difficult. When the probe moves upwards the solids are momentarily not homogeneously dispersed around the probe, which is an another factor influencing the results.

*Advantage:* If it is possible to analyse a cell every time the rake goes by, i.e., time normally lost could be used for calibration.

## 4.4 Portable probe calibration procedure

### 4.4.1 Description

A hand held single cell probe (§ 3.3) which can be lowered at any point in the thickener was used for this calibration method. By having a single cell and moving it through the thickener, only true changes in density and conductivity affect the results. The single cell can therefore be used to correct any of the rings of the stationary probe.

### 4.4.2 Methodology

To take profiles of the thickener using the portable probe, the following procedure was adopted:

↪ Find a suitable location on the catwalk from which to lower the probe into the thickener. The best location is just beside the industrial probe.

↪ Lower the probe until it is just in the froth and start collecting readings by each time lowering the probe a set distance (e.g 15.24 cm (6 inch)).

**Caution:** The probe can be caught by the rake, therefore the measurements have to be taken just after the rake passes by.

↪ When the bed is reached the readings are stable and the supporting line tends to go limp.

↪ Repeat the measurement on the other side of the probe.

The set of data obtained with the portable probe gives conductance as a function of depth. To correlate readings from the portable probe with those from the industrial probe, the conductance has to be converted to conductivity as was discussed in section 3. The following equation (i.e. portable probe cell calibration) was used:

$$\text{Conductivity} = -0.05748 + 5.548 * \text{conductance} - 0.0804 * \text{conductance}^2 * 0.2 \quad (4.6)$$

Then the conductivity has to be correlated to the depth of the industrial probe. The industrial probe begins collecting data at 45.48 cm from the top edge of the thickener, the

rings are spaced 10 cm, so the next data point is at 55.48 cm, then 65.48 cm etc. until 345.48 cm. In the current design the portable probe is started at 30.48 cm then collects data every 15.24 cm until the bed is reached. The data the portable probe collects are therefore at different depths than the data the multicell probe collects. To obtain conductivity data from the portable probe at the same depth as the industrial probe a program in C was written. The input is the data taken every 15.24 cm (6 inch), the output is the conductivity at 45.48 cm increased by 10 cm until 345.48 cm is reached.

```
#include math.h
#include stdio.h
#include stdlib.h

main()
{
    float depth_centimeter[31], data_cent[31];
    float depth_inch[21], data_inch[21];
    char file_name[25];
    int i,j;
    FILE *fp;

    get data
    printf("Input the original file name\n");
    scanf("%s" file_name);
    if((fp=fopen(file_name,"r"))==NULL)
    {
        printf("Wrong file name\n");
        exit(1);
    }
}
```

```
for(i=0;i<21;i++)
    fscanf(fp, "%f", &data_inch[i]);
fclose(fp);

    get depth_centimeter
if((fp=fopen("d_cent","r"))==NULL)
{
    printf("no file d_cent\n");
    exit(1);
}
for(i=0;i<31;i++)
    fscanf(fp, "%f", &depth_centimeter[i]);
fclose(fp);

    get depth_inch
if((fp=fopen("d_inch","r"))==NULL)
{
    printf("no file d_inch\n");
    exit(1);
}
for(i=0;i<21;i++)
    fscanf(fp, "%f", &depth_inch[i]);
fclose(fp);

printf("Input the saving file name\n");
scanf("%s" file_name);
if((fp=fopen(file_name,"w"))==NULL)
{
```

```

        printf("Wrong file name\n");
        exit(1);
    }
    j=0;
    for(i=0;i<21;i++)    for loop on the depth_inch
    {
        while the depth_centimeter value is in the range of two depth_inch value
        while(depth_centimeter[j]>=depth_inch[i]&&depth_centimeter[j]<=depth_inch[i+1])
        {
            // find the corresponding data_cent data
            // '\n' at the end of the line means change to another line
            data_cent[j]=data_inch[i]+(data_inch[i+1]-data_inch[i])
            (depth_inch[i+1]-depth_inch[i])*
            (depth_centimeter[j]-depth_inch[i]);
            fprintf(fp, "%f\n",data_cent[j]);    // save to the output file
            j++;    // next depth_centimeter data
        }
    }

    if(j<30)    // for the last two values
        for(i=j;i<31;i++)
        {
            data_cent[i]=data_inch[20];
            fprintf(fp, "%f\n",data_cent[j]);
        }
    fclose(fp);
    return 0;
}

```

Like any method it has advantages and disadvantages:

*Disadvantage:* It takes some time to collect data using the portable probe (20 minutes) and to compare the measurements with the multicell probe.

*Advantage:* Knowing what each ring is supposed to read by having an accurate second measurement is an ideal form of calibration. Even when the thickener is frozen this method can be applied, since right next to the probe the surface is kept open due to the constant movement of the probe to let the rake pass by.

From the four methods the last method is most reliable. It is recommended to use this method for calibration and to use the standardisation method if the portable probe calibration can not be carried out.

## **4.5 When to calibrate ?**

### **4.5.1 Based on deviation from calibrated profile**

A question remains, at what time interval does the probe need re-calibration. To answer this portable probe measurements were carried out during April and May 1998. These data were used to calibrate the industrial probe and compare to the depth vs. % solids profiles over time.

Figure 4.2 shows the calibrated data compared with uncalibrated data for April 1. The cell constants obtained for April 1<sup>st</sup>. with the calibrated data (method discussed in 4.4), were used throughout April. On May 1<sup>st</sup>. the depth vs. % solids profile was compared with a profile obtained with a calibrated multicell probe (Figure 4.3). It can be seen that the calibrated profile is far off from the not calibrated profile. Therefore the cell constants have to be updated more than once a month. Using the cell constants obtained on May 1<sup>st</sup>. the depth vs. % solids profiles of the multicell probe for May 4, 6, 8 and 11 (Figures 4.4 - 4.7) were obtained and each compared with its calibrated profile for that day. From the results



can be seen, that over time the two profiles start to differ from each other. On May 11 the difference is so large that new cell constants have to be used. Figure 4.8 shows the depth vs. % solids profile for industrial probe with cell constants used from May 11<sup>th</sup>, when this profile is compared to a profile obtained with a calibrated probe for that day it can be seen the difference is nil. The same trend is seen for a profile obtained one day later (Figure 4.9). However for May 20<sup>th</sup>. it can be seen that the profiles differ and new cell constants have to be used again.

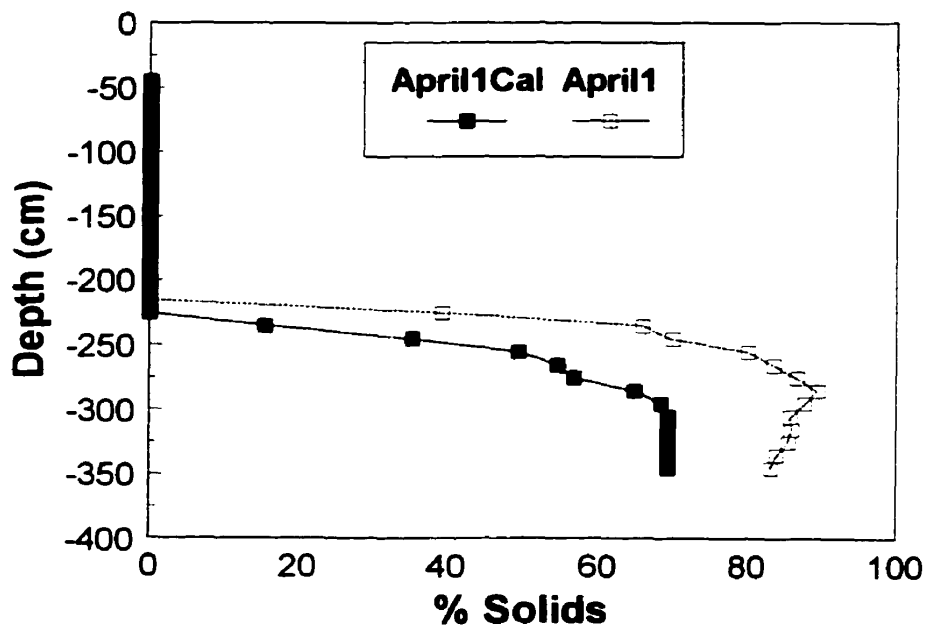


Figure 4.2: Freshly calibrated profile (■) for April 1 compared to that using cell constants of December 17 (□).

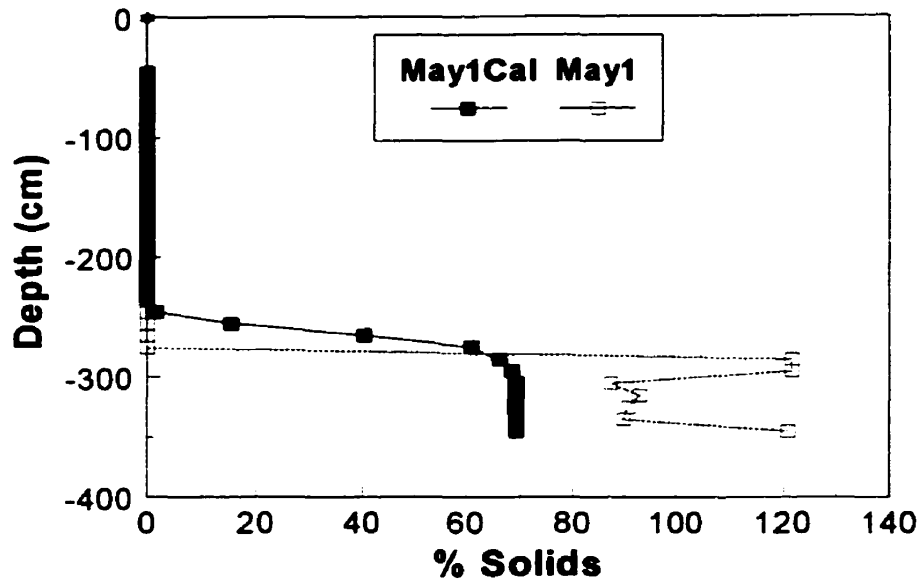


Figure 4.3: Freshly calibrated profile (■) for May 1 compared to that using cell constants of April 1 (□).

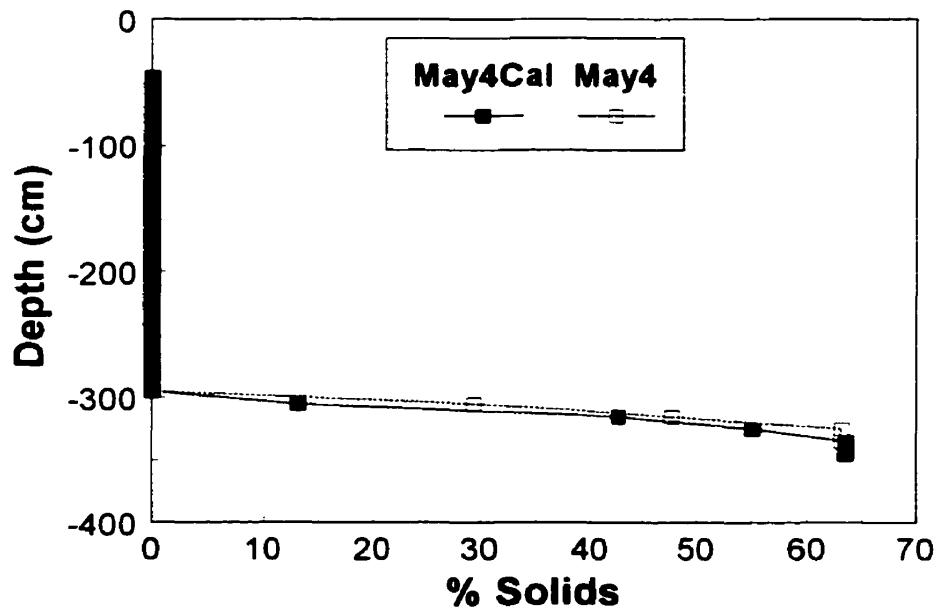


Figure 4.4: Freshly calibrated profile (■) for May 4 compared to that using cell constants of May 1 (□).

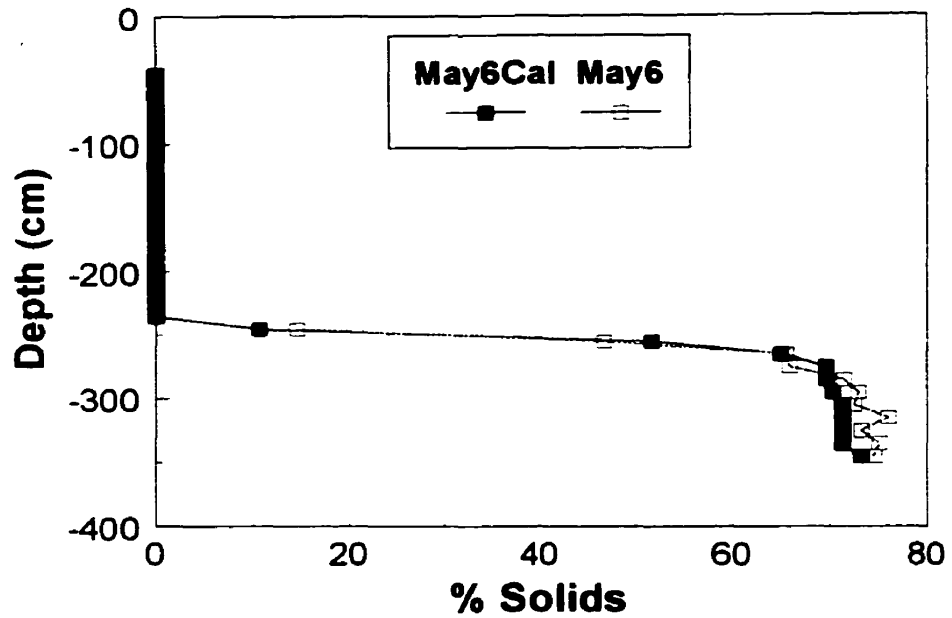


Figure 4.5: Freshly calibrated profile (■) for May 6 compared to that using cell constants of May 1 (□).

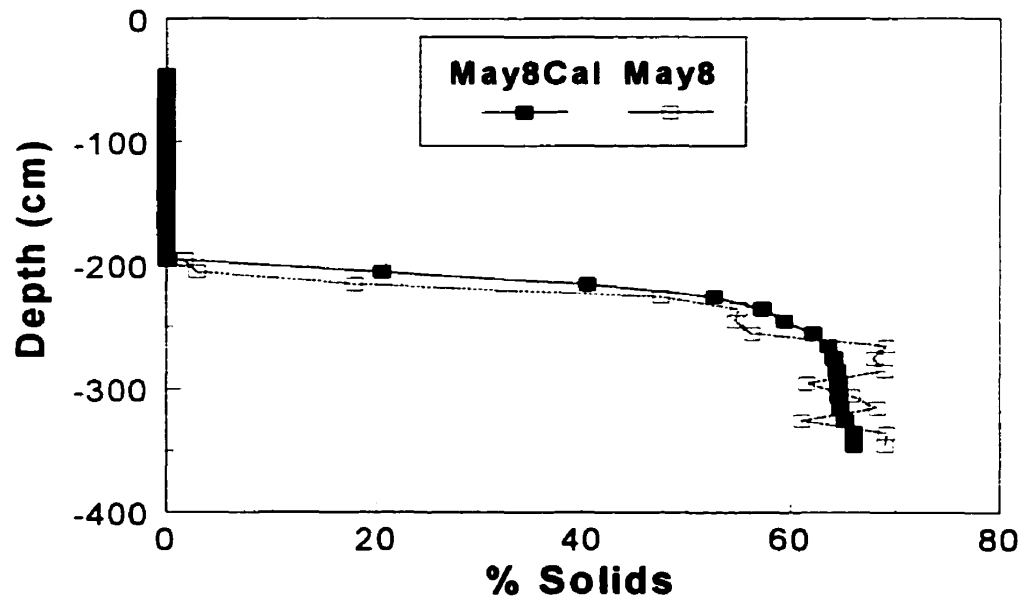


Figure 4.6: Freshly calibrated profile (■) for May 8 compared to that using cell constants of May 1 (□).

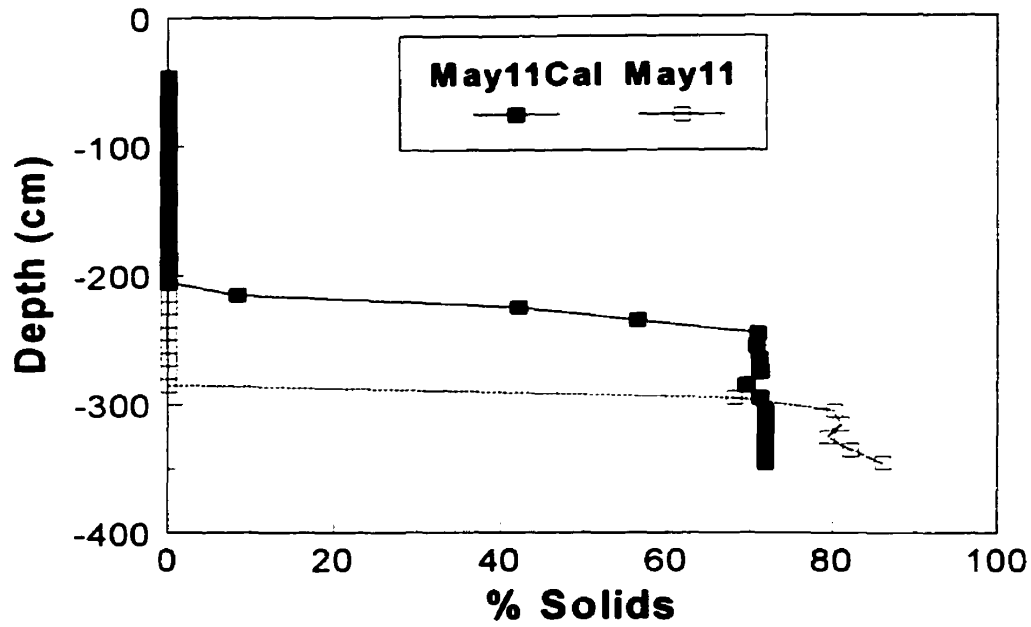


Figure 4.7: Freshly calibrated profile (■) for May 11 compared to that using cell constants of May 1 (□).

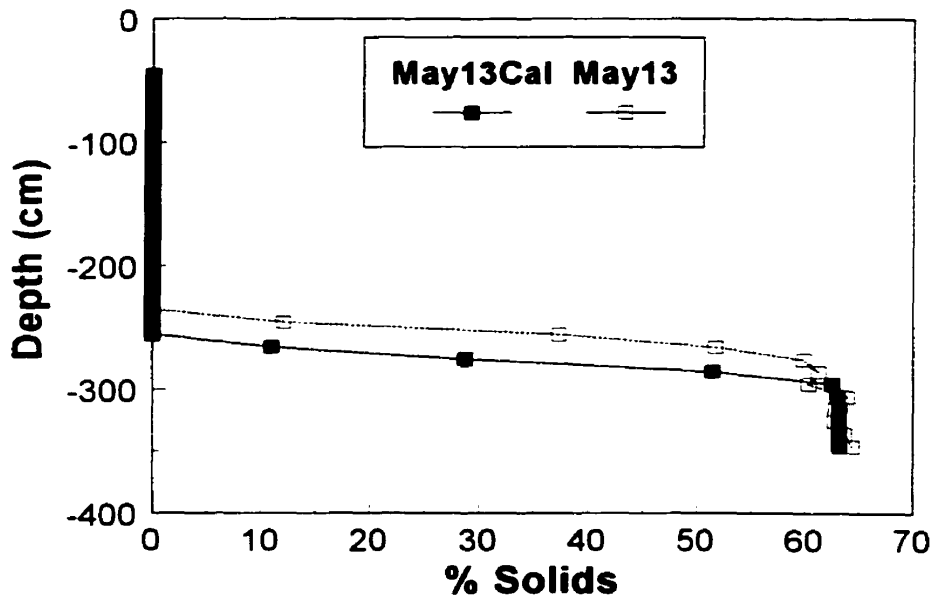


Figure 4.8: Freshly calibrated profile (■) for May 13 compared to that using cell constants of May 11 (□).

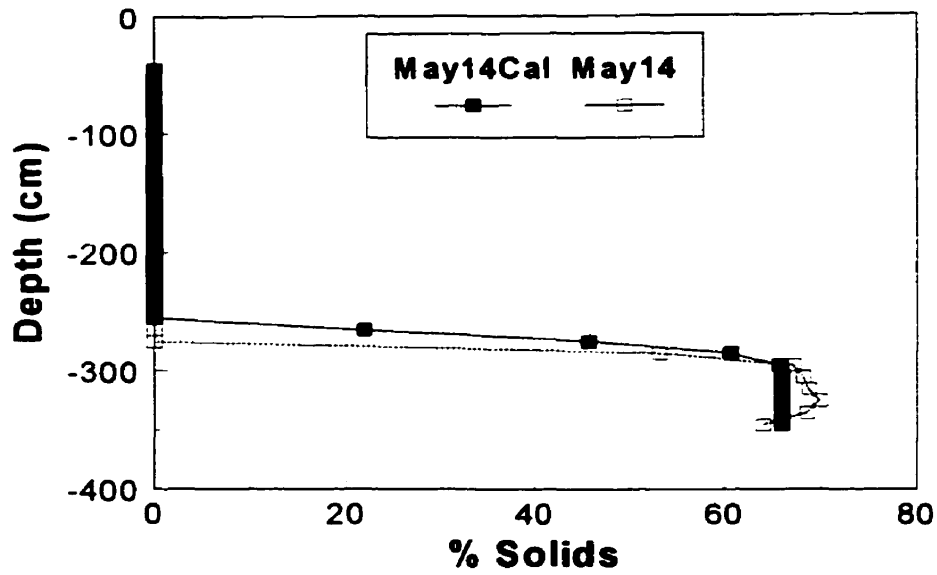


Figure 4.9: Freshly calibrated profile (■) for May 14 compared to that using cell constants of May 11 (□).

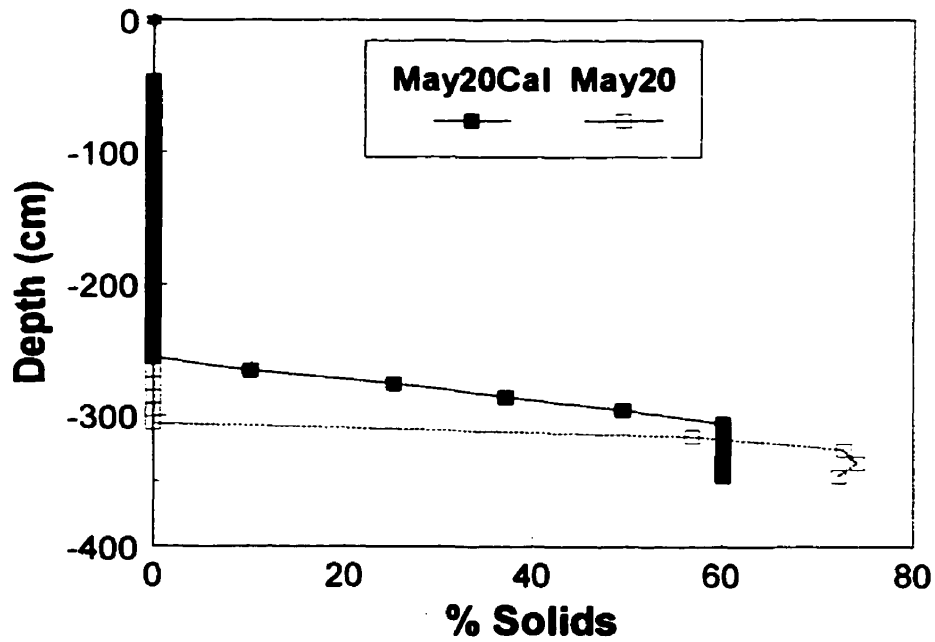


Figure 4.10: Freshly calibrated profile (■) for May 20 compared to that using cell constants of May 11 (□).

By inspection, it can be seen that the cell constants have to be updated around every 10 days to maintain a reliable profile.

#### 4.5.2 Based on bed height and U/F % solids

Other ways of establishing the time lapse between calibration is to look at the bed height (the technique to derive bed height is discussed in the following chapter, but for now only the results are given) and underflow % solids. Table 4.1 shows the bed height (derived from the Figures above) obtained with a freshly calibrated probe compared to a previously calibrated one (date given) also in table 4.1 are the value for U/F % solids.

Table 4.1: Bed height and U/F density for freshly and previously calibrated probe.

Date	Previous		Fresh	
	Bed height [cm]	U/F density [% solids w/w]	Bed height [cm]	U/F [% solids]
April 1, 1998	110.28 (Dec. 17,1997)	83.49 ( Dec. 17,1997)	70.28	68.31
May 1, 1998	80.28 (April 1,1998)	121.68 ( April 1,1998)	80.28	66.14
May 4, 1998	30.28 (May 1,1998)	62.29 ( May 1,1998)	30.28	63.56
May 6, 1998	110.48 (May 1,1998)	61.93 ( May 1,1998)	90.28	69.63
May 8, 1998	100.28 (May 1,1998)	69.10 ( May 1,1998)	100.48	62.19
May 11,1998	60.28 (May 1,1998)	80.19 ( May 1,1998)	100.28	67.11
May 13,1998	90.28 (May 11,1998)	59.85 ( May 11,1998)	70.28	60.09
May 14,1998	70.28 (May 11,1998)	67.07 ( May 11,1998)	70.28	65.75
May 20,1998	40.28 (May 11,1998)	72.74 ( May 11,1998)	60.28	60.16

It can be seen that for April 1 and May 11 and 20 both bed height and U/F density differ a lot. For May 1 it seems from the bed height data there is no problem, but the U/F

density is 121.682 %. So a combination of bed height and U/F density is a good measure for judging if a profile is reliable or not. This method also shows that calibration is needed around every 10 days.

The next chapter will focus on estimation of bed height (mud-line) in thickeners and the values given in Table 4.1 will be derived.

## CHAPTER 5

# BED HEIGHT ESTIMATION

In this chapter a 0-1 scale used to indicate the bed height [5-10] will be related to a true bed height. The true bed height is derived from manual measurements with a weighted rope and from the % solids profile the conductivity probe produces. The two methods to measure the bed height will be compared.

### 5.1 Manual bed height measurement

Bed height estimation forms an important part of thickener control. Currently bed height at Copper Cliff, Ontario Division of Inco Ltd. is measured by operators using a weighted rope. The rope is lowered into the thickener and when it becomes slack it is pulled out of the thickener and the bed height is measured (Figure 5.1). Some operations use a plexiglass graduated tube which is lowered into the thickener until the end of the tube is in the bed, the open end of the tube is then closed and the tube is being pulled out of the thickener. From the transparent tube liquid and solids can be distinguished and the bed height read off.





Figure 5.1: Manual technique to estimate bed height using rope with weight at the end.

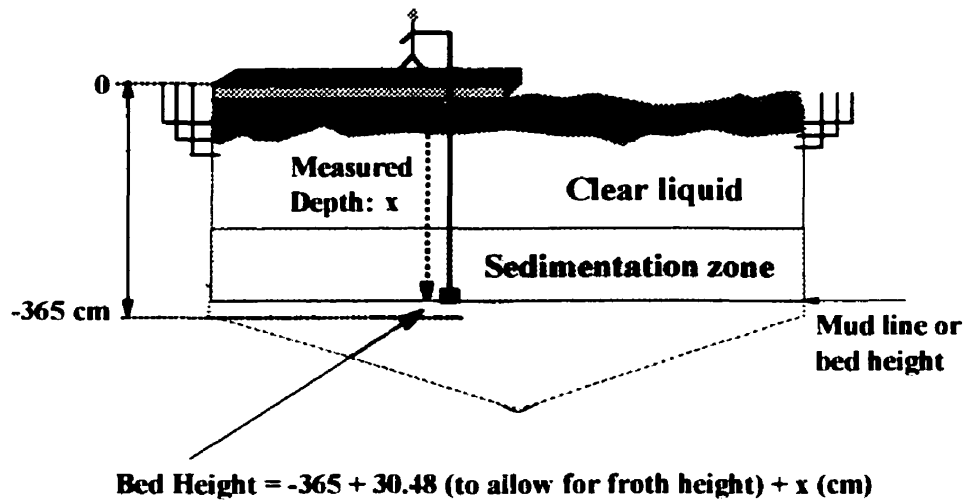


Figure 5.2: Example of bed height measurement using rope with weight. This particular thickener has a wall height of 365 cm.

It is important to define to what is the reference for the height of the bed. The operators at Copper Cliff, Ontario Division of Inco Ltd. use the top edge of the thickener as reference. Since the froth starts about 30.48 cm (1 ft) from the top edge of the thickener this should be added when taking a measurement (the rope only measures from the froth

down). The stationary probe starts 15 cm below the top froth layer, therefore the depth of the first measurement is -45.48 cm from the top (the top is taken zero, all depths are therefore negative).

These manual measurements are no guarantee against a dirty overflow, which occurred several times during this research, due to poor recognition of bed height. The techniques used by the operators only provide an indication of the bed height. It is time consuming and not on-line, so there are no continuous data available. Another problem is that in an outdoor thickener in a cold climate the the top layer can be frozen.

Due to the problems related to the manual measurement a method was needed to obtain a continuous estimation of bed height. The conductivity probe can detect the bed due to the change in conductivity. Early work by Probst et. al. [10] derived an algorithm to detect the bed. This algorithm produced a number between 0-1, called level. The algorithm is discussed below.

## 5.2 Level

A level (“interface”) was devised to give an indication of the position of the bed. This level is a number between 0-1. The level is obtained by dividing the thickener into three zone’s (Figure 5.3), each yielding an average % solids which is used to calculate the level from the following:

$$Level = \frac{Interface - Liquid}{Solids - Liquid} \quad (5.1)$$

In Figure 5.3 the level calculation can be seen for two data sets, one with a low the other with a high level. By using an average the effect of an error in one or two readings is dampened.

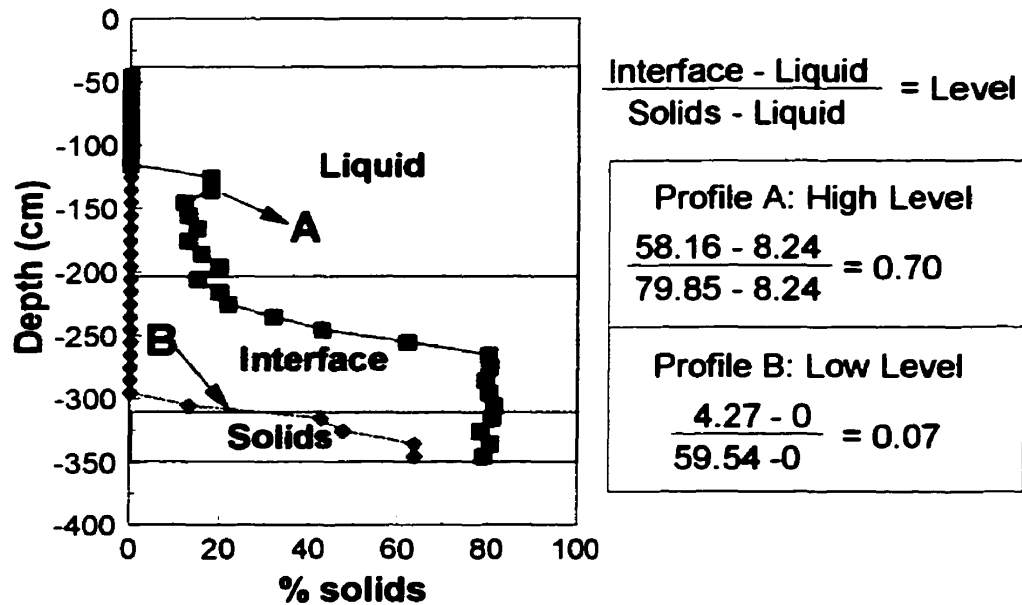


Figure 5.3: Level calculation

The three zones correspond to a predefined ring range. For example the probe used had 32 rings (=31 cells).

Liquid = cells 2 to 17

Interface = cells 18 to 27

Solids = cells 28 to 31

### 5.3 Converting level to true bed height

In this section a relationship between level and bed height in a thickener is established by comparing level with:

1. Manual bed height measurements.
2. Bed height measurement from % solids profiles.

### 5.3.1 Using manual bed height measurements

Manual bed height measurements were taken over a period and the corresponding 0-1 level is plotted against these in Figure 5.4. There are 5 linear plots, each plot representing a different predefined ring range to calculate the 0-1 level. It can be seen that it does not matter which predefined ring range is chosen in the sense that the relationship is linear. For each ring range an equation can be determined by regression to convert the 0-1 level to bed height. Note that the bed height given in Figure 5.4 is the bed height from the bottom of the thickener (-365 cm (12 ft.) in Figure 5.2).

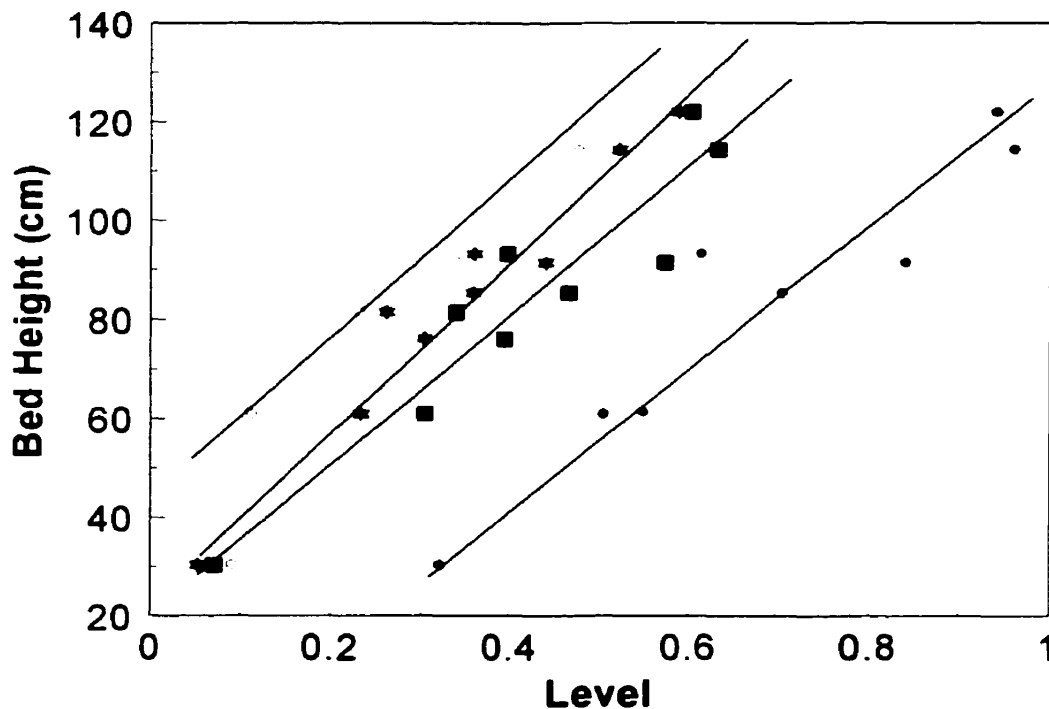


Figure 5.4: Level vs. manual measured bed height.

As can be seen from Figure 5.4 there are some points that deviate. This is due to the manual measurement. As was discussed this technique is not very accurate. The conductivity measurements themselves can be again used to obtain a correlation between the 0-1 level and the bed height.

### 5.3.2 Measurement of bed height from % solids profile

The bed height can be derived by inspecting the depth vs. % solids profile. A program was written in C, which reads in a data file called x.dat containing the % solids. The program will find the depth where the mud-line starts and the value of % solids associated with the depth. The program is given below.

```

#include <math.h>
#include <stdio.h>
#include <stdlib.h>
#define y0 45.48 // the reference depth

void find_point(float *); // the function to find the changing point

main()
{
    FILE *fp; // file pointer
    float x[31];
    fp=fopen("x.dat","r"); // open the data file
    if(fp==NULL) // if the file does not exist
    {
        printf("cant find x.dat");
        exit(1);
    }
    for(int I=0;I<31;I++) // import the data
        fscanf(fp, "%f",&x[I]);

    find_point(x); // find the point

```

```

    return 0;
}
void find_point(float *p)           // p is the array point to the data
{
    int i=0;
    float j,k, depth;
    int quit=0;
    while(*p==0)                   // skip all the 0 values
    {
        p++;
        i++;
    }
    while(!quit)
    {
        j=*p;                       // j is the current point
        k=*(++p);                   // k is the next point
        if((fabs(j-k)) <= 0.05*j)  // if the difference less than the error
        {
            depth=y0-i*10;          // output, since i starts from 0, the
            // position should be i+1
            printf("the valued changed at the %dth position\n", i-1);
            printf("depth: %f\tx_value: %f\n",depth, j);
            quit=1;
        }
        i++;                         // next point
    }
}

```

Figure 5.5 plots the bed height obtained with the above program against level (Again the bed height is from the bottom of the thickener). It can be seen that the data fits a linear relationship which appears to be better than using the manual bed height measurements. The Figure also shows that the same level gives overall a lower bed height than bed height obtained with the manual method. This is due to the difference in weight between the rope and industrial probe. The weight on the rope is simply not heavy enough to penetrate a high density slurry. If the operators can be persuaded the method discussed in this paragraph, using the % solids profile, should be used in the future.

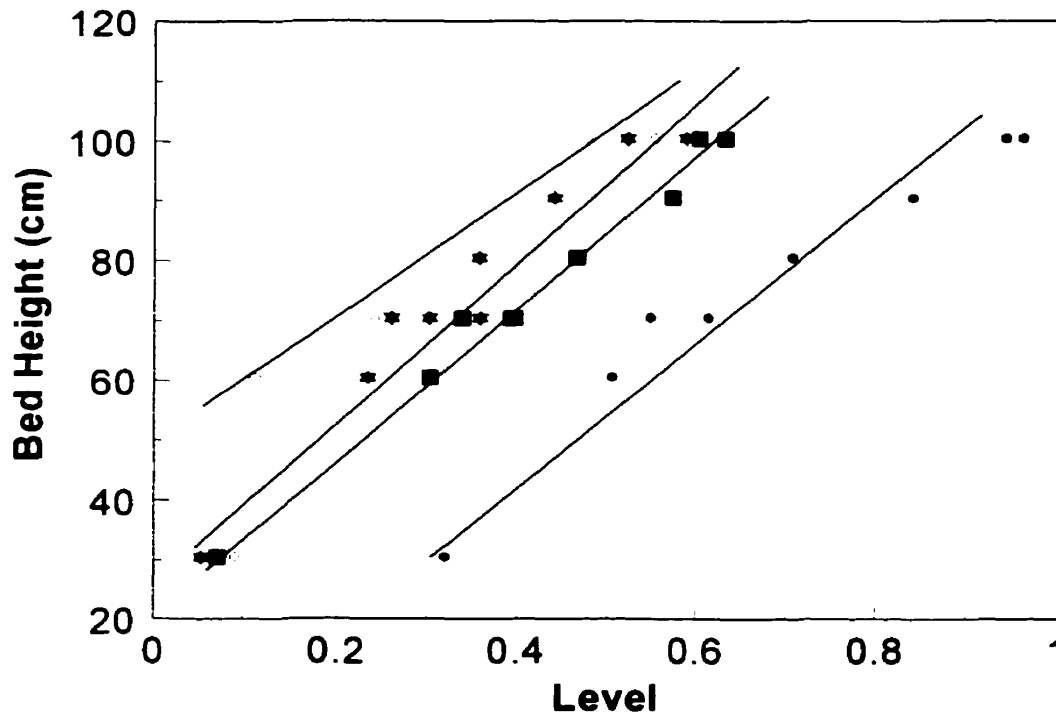


Figure 5.5: Level vs. bed height measured from % solids profile.

In the next chapter several parameters that influence thickener behaviour are discussed in relation to one another. Among them is the bed height, derived from the probe.

# CHAPTER 6

## OBSERVATIONS ON THICKENER BEHAVIOUR

In this chapter the effects of some of the parameters that influence thickener behaviour are described. The parameters discussed are torque, flocculant rate, load and mud-line or level of the bed.

### 6.1 Overflow

For a period of two months (April and May 1998) the pH and the % solids in the overflow of the thickener was monitored (Figure 6.1). From the operators, data on flocculant rate were collected. The results are summarised in Figures 6.2 and 6.3.



Figure 6.1: Overflow of thickener.



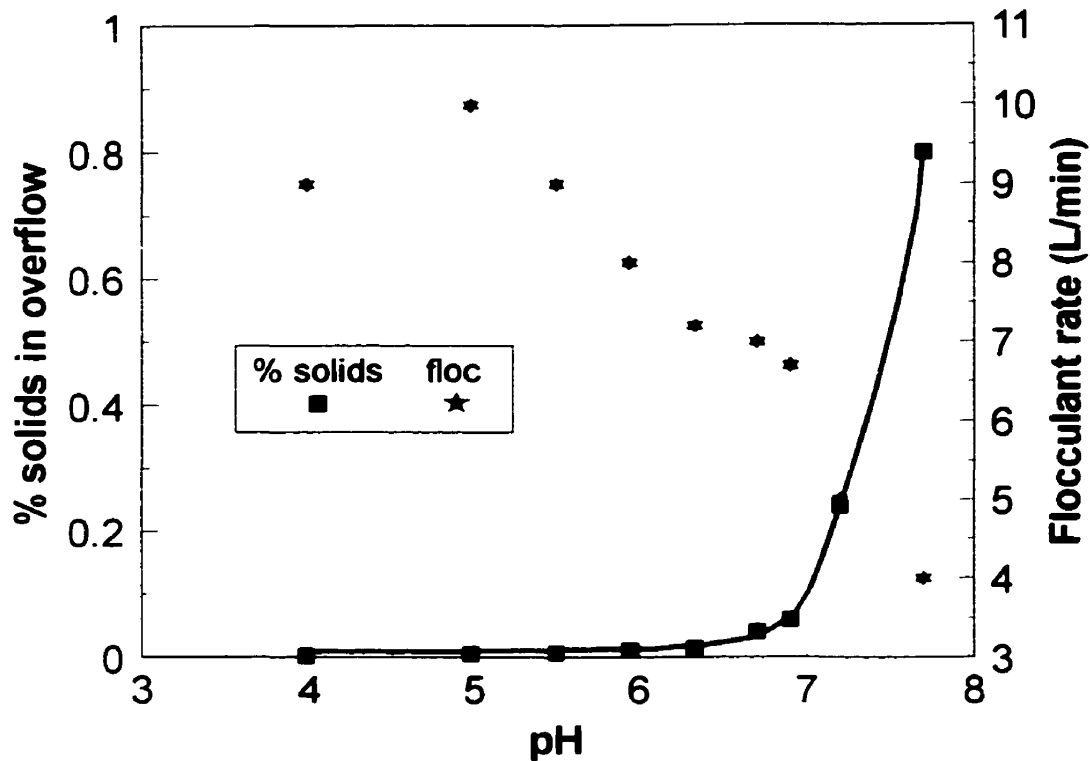


Figure 6.2: Relation between flocculant rate, % solids and pH during normal conditions and including an extreme condition (0.8 % solids).

Figure 6.2 shows how % solids depends on pH. We can see that there is a parabolic relationship. There is also a relationship between the % solids in the overflow and the flocculant rate: when the increase in % solids corresponds to a decrease in flocculant rate. An important point is that flocculant rate is an independent variable, it does not change with pH. However the pH and flocculant rate are linked. The Copper Cliff plant, Ontario Division of Inco Ltd. confirmed that more lime is added when the flocculant rate is decreased.

Flocculant is added when a more rapid settling of solids is desired. Flocculation involves the formation of loose agglomerates and relies upon molecules of reagent acting

as bridges between separate suspended particles. The reagents used to form the bridges are long chained organic polymers (polyelectrolytes). The majority of these are anionic in character. However since most suspensions encountered in the mineral industry contain negatively charged particles, one would expect that cationic polyelectrolytes, which would adsorb electrostatically on the particle, would be more suitable. For bridging, the polymer must be strongly adsorbed and this is promoted by chemical groups having good chemical bond characteristics, such as amide groups. Anionic polyelectrolytes have a higher molecular weight and are less expensive, which promotes their usage.

The mode of action of the anionic polyacrylamide depends on a segment of the long molecule being adsorbed on the surface of a particle, leaving a large proportion free to be adsorbed on another particle, so forming a molecular linkage, or bridge, between particles (Figure 6.3). Fine solids benefit from the addition of flocculant since they can then form a large agglomerate and settle faster. Due to their higher settling velocity they do not report to the overflow. This concept is illustrated by the results in Figure 6.2. It seems that an increase in solids reporting to the overflow results from a decrease in flocculant addition,

and is also a result of an increase in pH (since flocculant rate and pH are linked). Although no size analyses have been done on the solids reporting to the overflow it is expected that they are mostly the fine sizes.

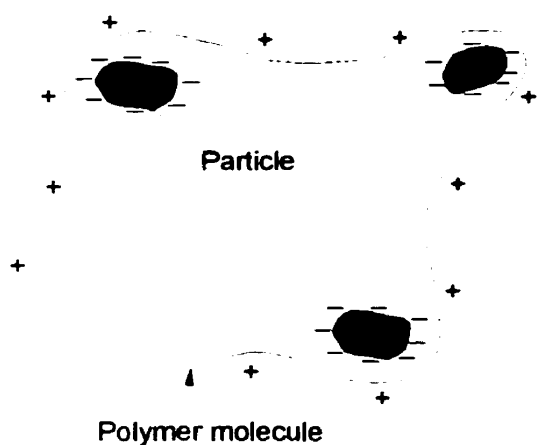


Figure 6.3: One linkage of an anionic polyelectrolyte.

From Figure 6.2 it can be seen that one point shows a very high % solids reporting to the overflow in comparison to the rest. This was because one of the thickeners (2A) had been damaged in the winter due to ice forming on the froth. The ice build-up was such that at one point it fell through the froth damaging the raking system. It was decided to pump the entire contents of thickener 2A to thickener 1A (used for the test work). The material was added via a pipe from the top in the thickener (see Figure 6.4). The pH was increased with lime addition and at the same time the amount of flocculant added was decreased. Due to the extra feed, the fine particles had no time to settle and reported to the overflow. To prevent a dirty overflow in this case the flocculant rate should have been increased. In fact the flocculant rate was increased after a day and % solids in the overflow did decrease.

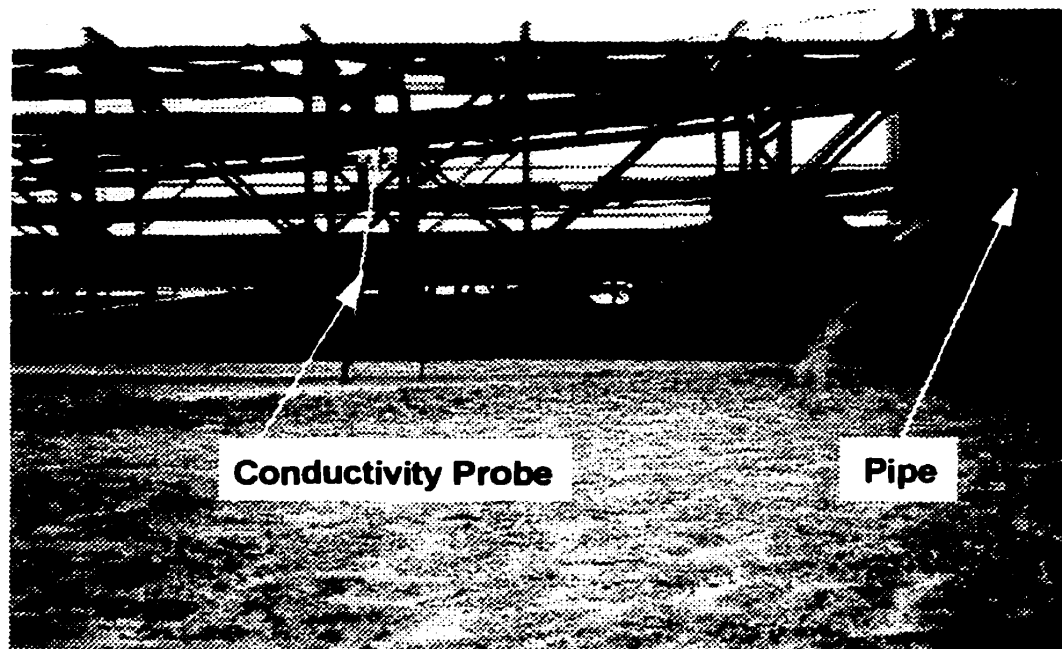


Figure 6.4: Addition of material through pipe above the thickener.

The relationship between % solids and pH is seen in Figure 6.5:

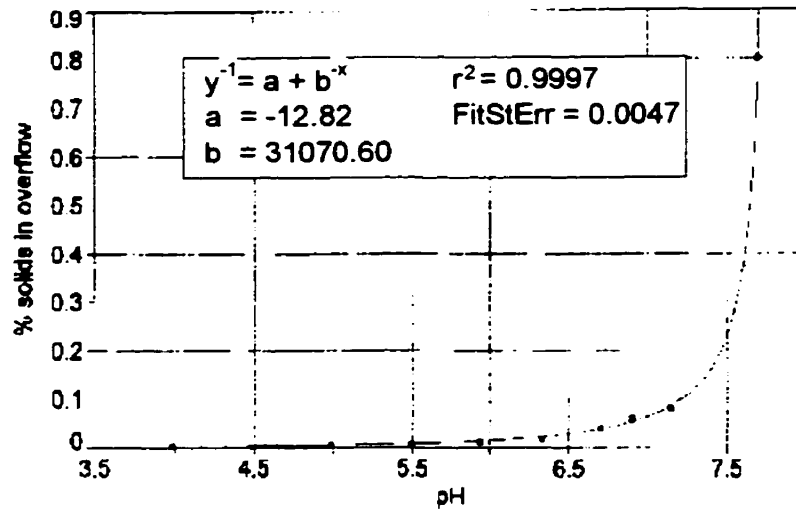


Figure 6.5: Relationship between % solids in overflow and pH for normal conditions with data added for an extreme condition (0.8 % solids).

The equation was verified, see Table 6.1.

Table 6.1: Results of predicted % solids and % solids measured in the overflow.

Date	pH	Predicted % solids	Measured % solids
23-4-1998	4.76	0.0040	0.0039
29-4-1998	6.18	0.0194	0.0180
01-5-1998	5.94	0.0145	0.0148
13-5-1998	5.5	0.0088	0.0089
14-5-1998	5.46	0.0084	0.0083

Flocculant is expensive and operators tend to delay adding it. Also, to inspect the operator has to go to the overflow site. This is supposed to be done 6 times per 24 hours,

but investigation of the charts over 8 months revealed that this was many times neglected. Therefore it would be useful for the operator to have a relationship with flocculant rate that would predict % solids in the overflow. Such a relationship is shown in Figure 6.6. The equation has been verified to see if the predictions are accurate (Table 6.2). Due to the limited time available to take measurements it is recommended more test work is carried out.

Table 6.2: Results of predicted % solids and % solids measured in the overflow.

Date	Flocculant	Predicted % solids	Measured % solids
23-4-1998	10	0.0030	0.0039
29-4-1998	7.8	0.0178	0.0180
01-5-1998	8	0.0150	0.0148
13-5-1998	8.5	0.0098	0.0089
14-5-1998	8.5	0.0098	0.0083

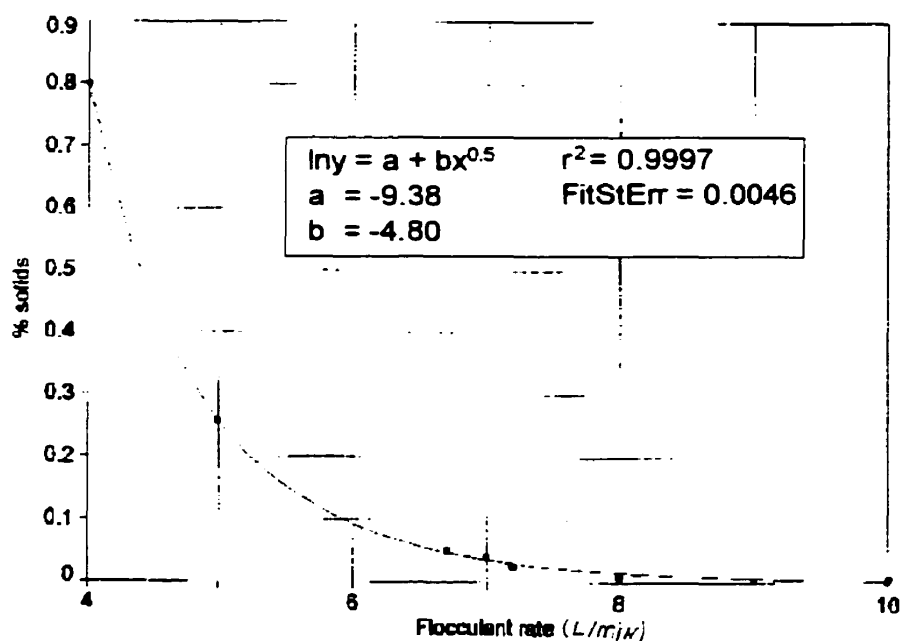


Figure 6.6: Relationship between % solids in overflow and flocculant rate for normal

conditions with data added for an extreme condition (0.8 % solids).

As will be discussed, the relationship established above is not valid for excess flocculant addition, in which case the quality of the overflow will decrease.

## 6.2 Torque - Flocculant

The relationship between torque and flocculant addition was monitored over an extended period. Figures 6.7 - 6.13 give the data for the months November 1997 until May 1998 taken at 8 pm. Appendix C gives also the data for 12 am and 4 am.

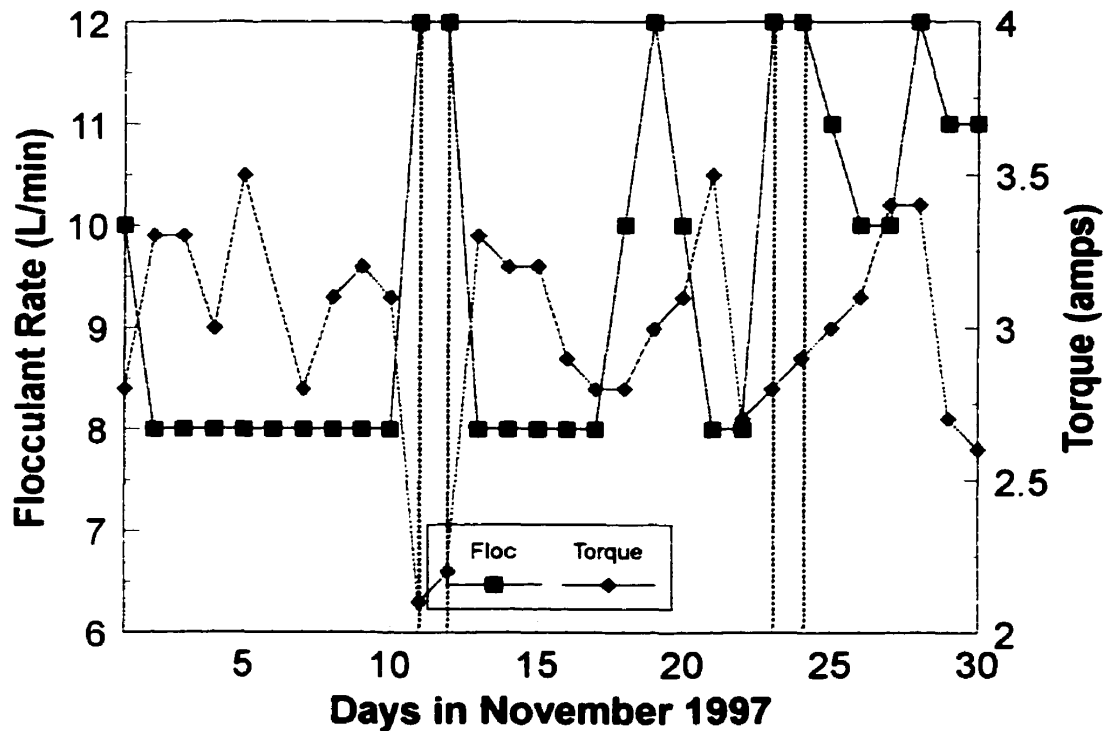


Figure 6.7: Flocculant rate and torque as a function of time for November 1997.

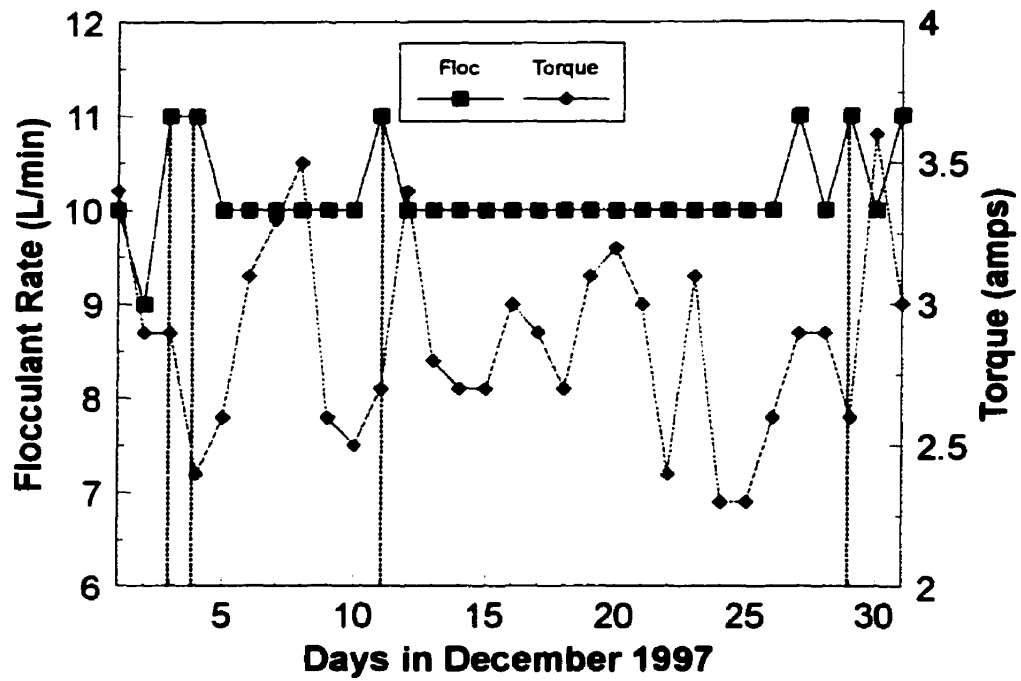


Figure 6.8: Flocculant rate and torque as a function of time for December 1997.

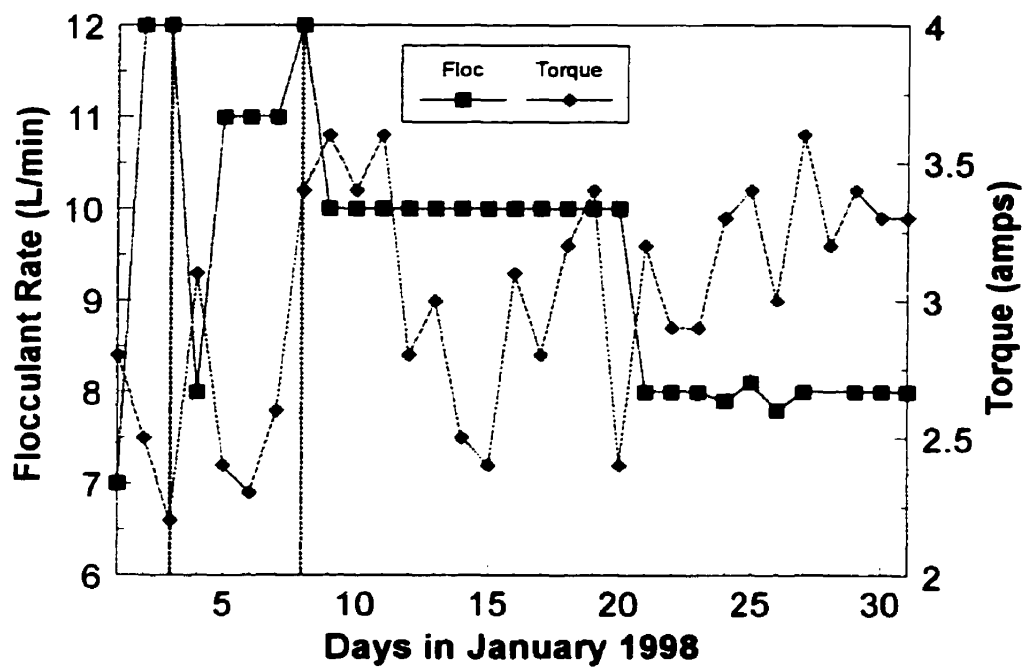


Figure 6.9: Flocculant rate and torque as a function of time for January 1998.

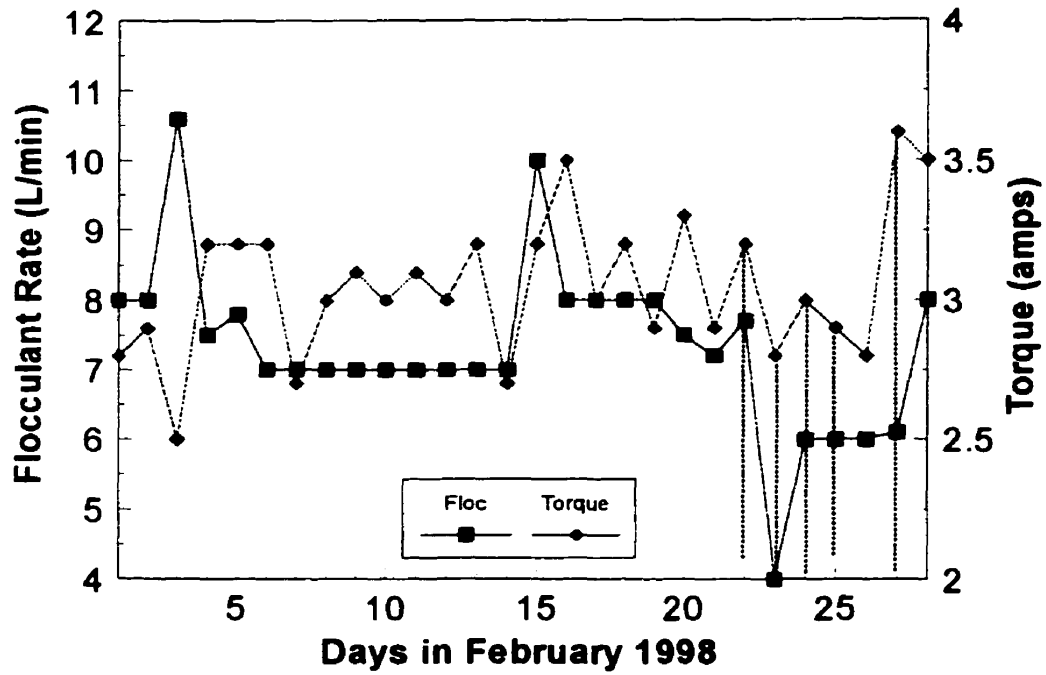


Figure 6.10: Flocculant rate and torque as a function of time for February 1998.

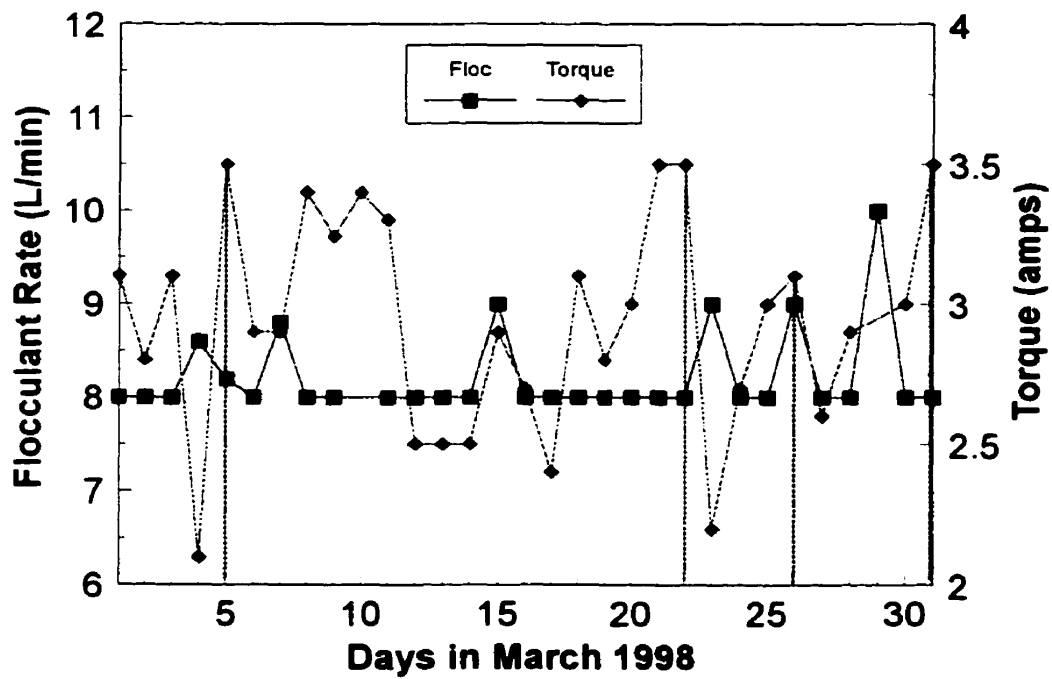


Figure 6.11: Flocculant rate and torque as a function of time for March 1998.



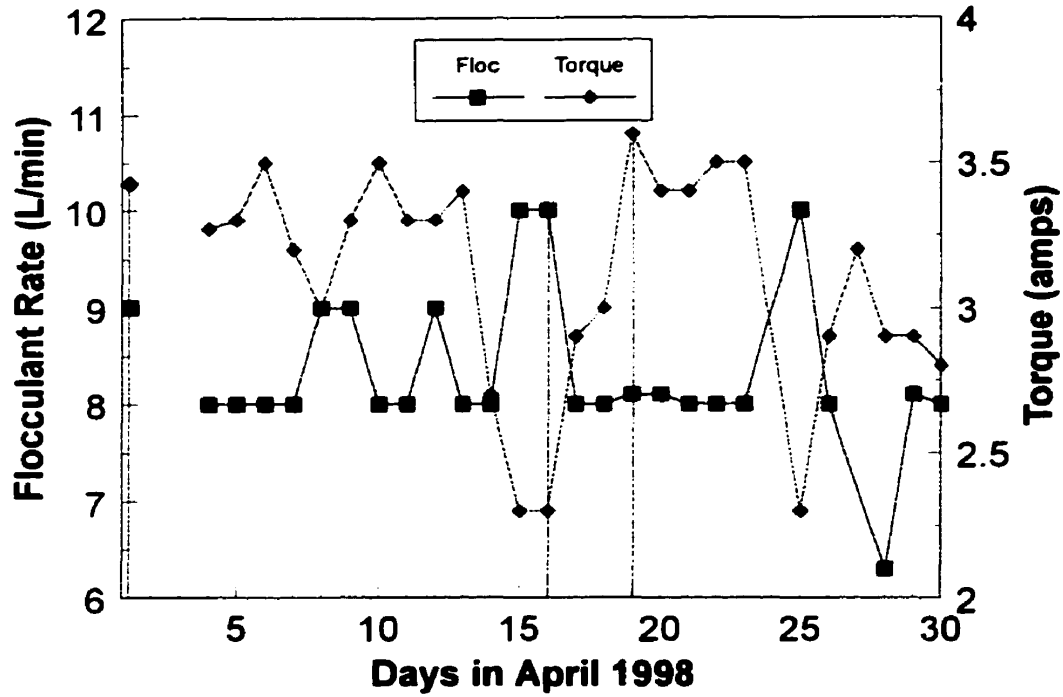


Figure 6.12: Flocculant rate and torque as a function of time for April 1998.

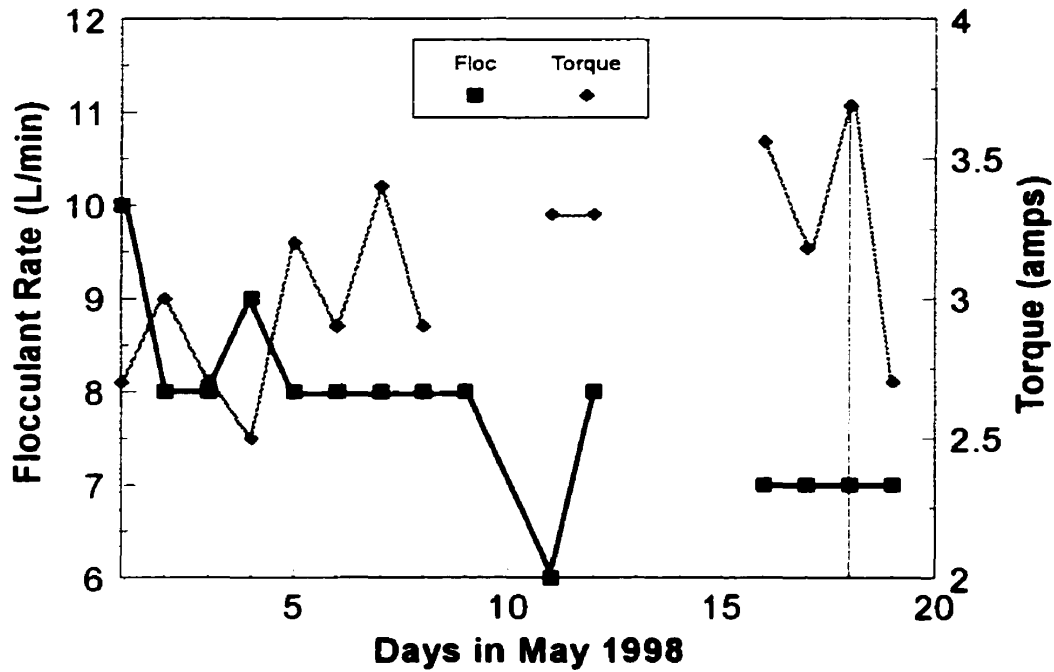


Figure 6.13: Flocculant rate and torque as a function of time for May 1998.

It can be seen that when the flocculant rate is high the torque is generally low. However when the flocculant rate is low, the torque can be either high or low. This can be explained by the fact that flocculants not have only a large influence on the settling velocity as discussed in §6.1, but also on the packing of the solids. Flocs formed by flocculants of high molecular weight are relatively large and loose entraining water within the structure. Smaller flocs are formed by lower molecular weight flocculants, which have a higher shear-resistance and the water can be easily pushed out to make the bed more compact. The rakes also play an important role in eliminating water.

Due to the fragile nature of flocs, they can be partially disrupted by the rakes. The maximum effect of a flocculant is achieved at an optimum dosage rate and pH; excess polymer can cause dispersion of the particles due to floc breakdown. We can see this effect from the results. When the flocculant rate is 12 the effect of the flocculant is nil and this can cause compaction of the bed (high torque) and dirty overflow due to the increase in bed height. This can be detected by the probe. In Figure 6.14 we can see the depth vs % solids profile for 23 November 1997, when the flocculant rate was 12 L/min. The probe is detecting a bed height of 110 cm ( $\pm 3.5$  ft), measured from bottom, and an interface between clear water and loose solids at 275 cm (9 ft.), since the fine particles do not form flocs and settle fast. Also the % solids in the bed is very high at 80%.

On two occasions over the last 6 months excessive flocculant addition caused formation of large flocs, and made the bed expand and become "loose", resulting in a dirty overflow (11/12 November 1997 and 3 January 1998). This was detected by the probe. Figure 6.15 shows the data for 11/12 November. The flocculant rate was 12 and the torque very low (2.2 amps). It can be seen from the % solids vs. depth profiles for those two days that the bed was loose with a % solids of only around 63 %. The bed height is 61 cm (2 ft.) and the sedimentline is at 275 cm (9 ft.).

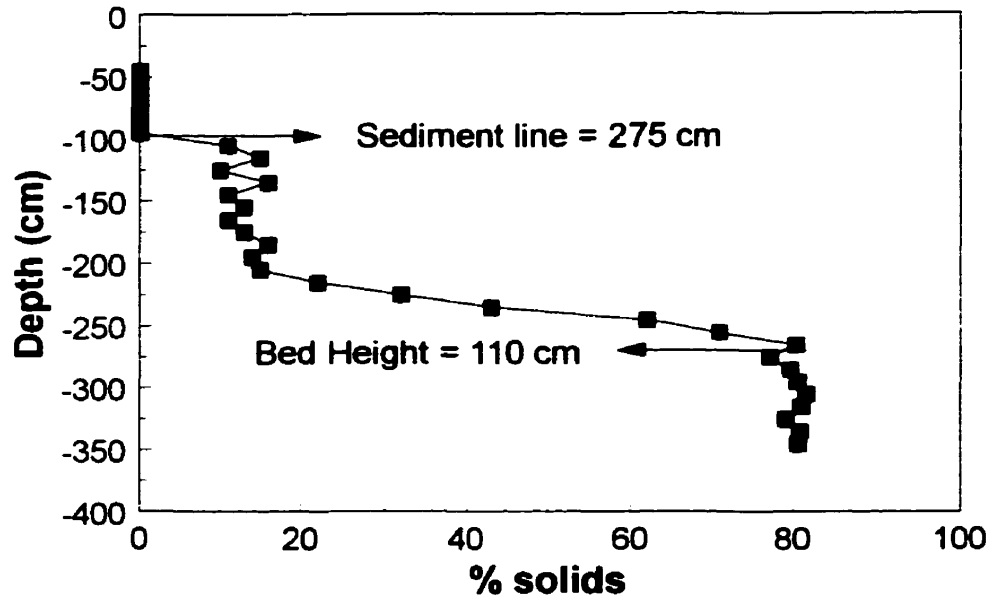


Figure 6.14: Depth vs. % solids profile for 23 November 1997, high flocculant addition.

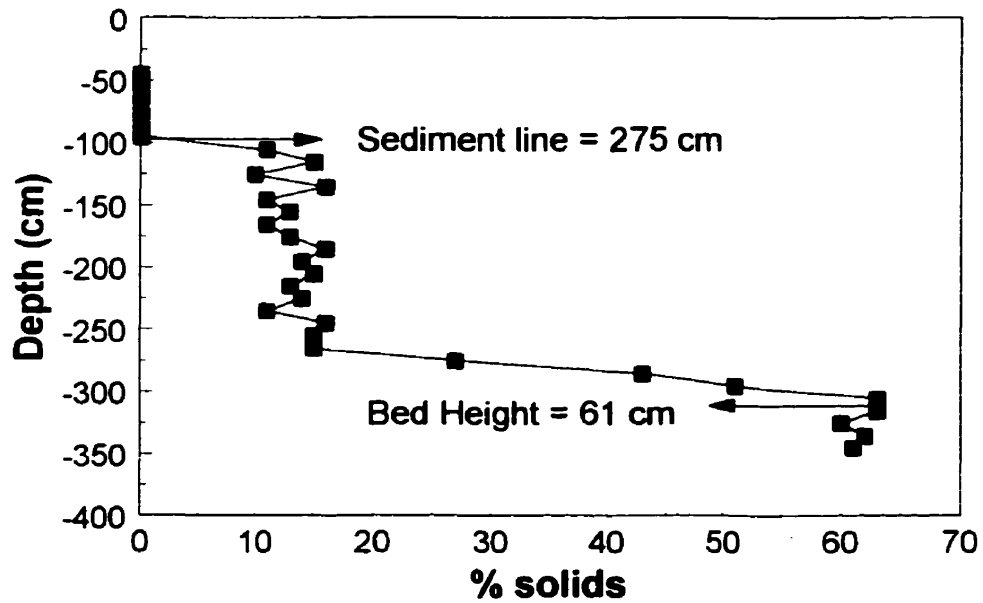


Figure 6.15: Depth vs. % solids profile for 11/12 November 1997, high flocculant rate.

High addition of polyelectrolyte causes generally rapid settling and prevents fines going into the overflow but in some cases it can also cause dirty overflow due to a high, loose bed. Low flocculant rate (6-8) and a high feed rate can cause a high compaction of the bed associated with a high torque. Over time when the solids accumulate, the bed will become higher. This effect is seen with the probe. Figure 6.16 gives the depth vs. % solids profile for 31 March 1998, the flocculant rate is 8 (defined as low) and the torque is high at 3.5 amps. The underflow % solids was 80% and the bed height 107 cm (3.5 ft), the sedimentline was at 244 cm (8 ft.).

When both flocculant rate and torque are low it means that either the thickener is empty or the feed rate has decreased. A general relationship between flocculant rate and torque can be seen from the results and is summarized in Table 6.3.

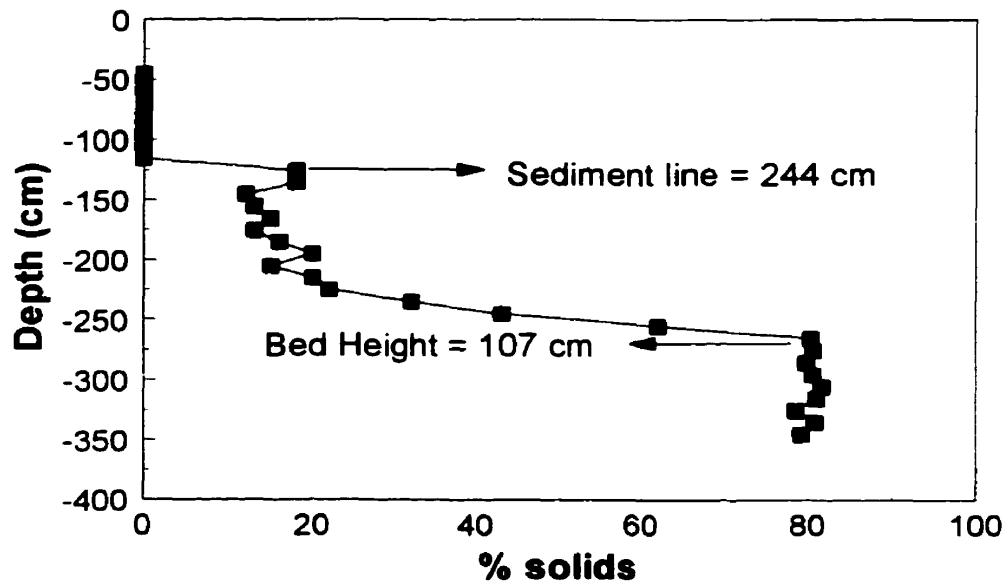


Figure 6.16: Depth vs. % solids profile for 31 March 1998.

Table 6.3: General relationship between flocculant rate and torque.

<b>Torque</b>	<b>Flocculant rate</b>	<b>Bed characteristics</b>
low	low	low, not compacted
low	high	high, not compacted
high	extremely high	high, compacted
high	low	low or high, always compacted

As can be seen from the results the amount of flocculant has a large influence on the quality of the overflow. At places where the overflow needs further treatment it could turn out to be unnecessary in the future with good process control and understanding the behaviour of the parameters influencing the amount of solids in the overflow.

### 6.3 Observations on load - bed height - U/F density

Three parameters that influence thickener behaviour, load, bed height and underflow density, were monitored in May 1998. They have been plotted in Figure 6.17. The underflow density was low for the entire period, around 62 % solids. The load which has been reported higher than 2500 tonnes at certain times [38] can be considered low (800 tonnes) to moderate (1700 tonnes). The bed height showed higher values for May 8 and 11. It seems there is a trend between bed height and load, when one goes up the other goes up to and vice versa. Further for May 11 the load was increased for three 4 days but the flocculant addition was low (Figure 6.13). The solids settled mainly without the aid of flocculant, increasing the bed height and the torque slightly. There was not a lot of compaction since the underflow density stays low. Unfortunately the graph shows inconclusive data. It was not possible to collect every day to obtain a continuous set of data. Therefore it is hard to draw conclusions about trends at this stage.

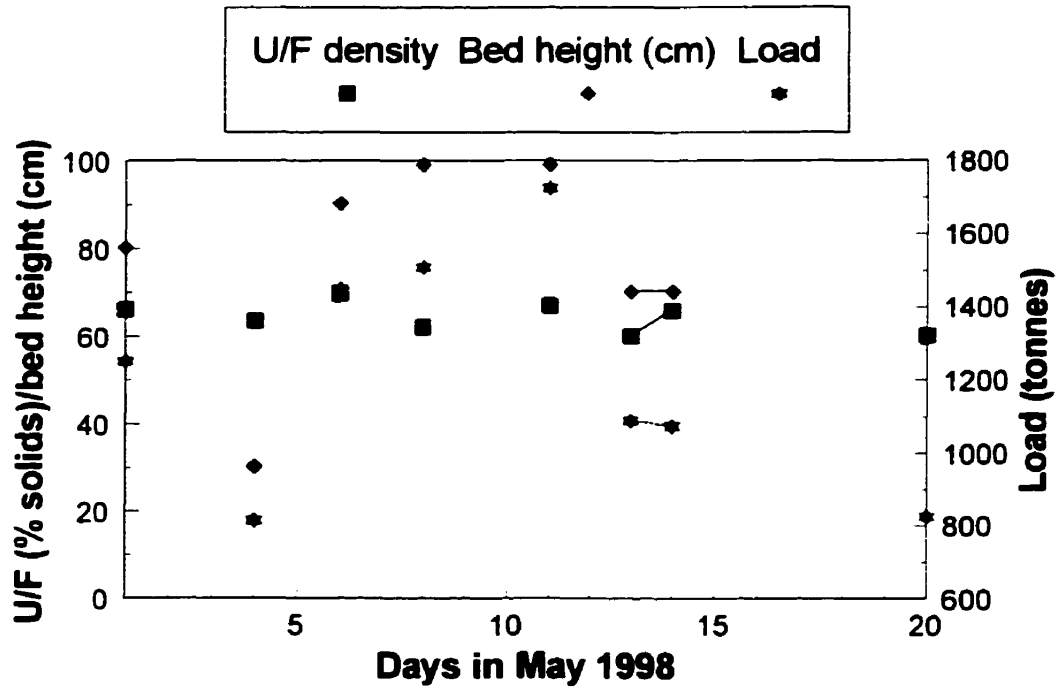


Figure 6.17: Underflow density, load and bed plotted for days in May 1998.

# CHAPTER 7

## CONCLUSIONS AND RECOMMENDATIONS

In this chapter, conclusions are given in the first section, followed by some recommendations for future work.

### 7.1 Conclusions

#### 7.1.1 Calibration procedure

1. The portable probe calibration method is the best method to calibrate the stationary probe;
2. Calibration with the portable probe is recommended every 10 days;
3. When the portable probe method can not be carried out the standardisation method can be used for a short period of time.

#### 7.1.2 Bed height estimation

1. The 0-1 scale has been transformed to a true depth with the use of:
  - a) manual bed height measurements (weighted rope method used by the operators);
  - b) software reading the mud-line from depth vs. % solids profile.

Both methods show a linear relationship between level and bed height. The linearity is independent of the ring range chosen for selecting the three zones; the equation changes, but the linear relation stays the same.

2. Comparing manual with profile method showed that the manual bed height measurement is less accurate. It is influenced by:

- a) human error;
- b) weather (frozen surface, unable to lower weighted rope);
- c) weighted rope has difficulty penetrating a high density slurry, which means that it can give a bed height higher than in reality.

Due to the errors that can occur in the manual bed height measurement a relation between the 0-1 scale and the bed height obtained from the % solids profile is recommended.

### **7.1.3 Observations on Thickener Behaviour**

#### ***- Overflow***

A relationship has been established between the % solids in the overflow and the flocculant rate, a higher flocculant rate results in less solids reporting to the overflow. However this relationship is not valid for excess flocculant addition.

#### ***- Torque-Flocculant***

1. High addition of flocculant (between 9-11) results in a loose bed and a low torque. The bed is high.
2. Excess flocculant addition (12) generally is insensitive, and results in a high compacted bed with a high torque.
3. Low flocculant addition (6-8) can result in a low torque and a loosely compacted bed. It can also result in a high torque which means the bed is compacted (the bed can be high or low).



### **- Bed height-Load-U/F Density**

There is inconclusive data to form conclusions about trends. It only seems that bed height and load are related.

## **7.2 Recommendations**

The following suggestions for future work are given:

1. To model the parameters that influence thickener behaviour many more tests have to be done on-site. Communication with the operators over an extended period of time is needed to relate the operators decisions, like increasing feed rate, emptying the thickener etc. with the parameters influencing thickener behaviour.

2. It could be seen that a dirty overflow resulted from a high sediment line. Therefore more attention should be given to the fact that the conductivity probe can also register the sediment-line (as well as the mud-line). The detection of the sediment-line could be build into the data acquisition program.

3. Finalise the Visual Basic program.

Boundaries have to be set to where the sediment-line or mud-line can rise, above this boundary an alarm should be sounded to warn the operator.

Including a year in the file would make the system more user independent. A year can be introduced by connecting Visual Basic to a database, like Oracle, retrieving the systems time from this software.

4. It could be seen from the results in chapter 4, that the % solids starts to deviate soon after calibration. This is because Maxwell's model (conductivity to solids) is not valid for the high % solids encountered in a concentrator thickener. The model has to be investigated and anew model derived to better estimate the % solids.

5. To make cleaning the probe easier it should be on a swivel, to allow easier lifting and lowering of the probe.
  
6. To allow the stationary probe to collect profiles at every point in the thickener a rail can be added to the catwalk to allow the probe to be moved to any position desired along the catwalk.
  
7. At the moment a board is being built to replace the conductivity meter and computer. The entire data collection will be done via this board. The advantages are it is more suited to industrial environments and is more compact.
  
8. Introducing the conductivity probe in a variety of thickeners to fully explore its potential.

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# Appendix A

## QUICK BASIC PROGRAM FOR DATA ACQUISITION

'PROGRAM FOR CONDUCTIVITY PROBE IN THICKENER 1A  
'INCO BOOSTER STATION OF COPPER CLIFF, ONTARIO DIVISION OF  
INCO LIMITED (SUDBURY)

DIM d%(10), LT%(10), x%(8)

DIM cond(35), cellconst(35), corrsolids(35), solids(35), solidsv(35), flgbr(35),  
x(8)

DIM histday(500), histday2(500), histweek2(2500), histweek(2500)

DIM profweek(35), profday(35)

DIM nochange(35)

COMMON SHARED d%(), LT%(), S

DECLARE SUB das8 (md%, BYVAL num%, fl%)

DECLARE SUB delay (ti)

ON KEY(1) GOSUB 399

KEY(1) ON

```
FOR q = 0 TO 3
    OUT (&H100 + q), 0
NEXT q
FOR j = 1 TO 8
    x(j) = 0
NEXT j
daytot = 0
tot = 0
flgsp = 0
flgsav = 0
FOR j = 0 TO 30
    flgbr(j) = 0
NEXT j

CLS
SCREEN 9
COLOR 3, 8
flgbr = 0

md% = 0
BADR% = &H300
fl% = 0
CALL das8(md%, VARPTR(BADR%), fl%)

md% = 19
d% = 9
fl% = 0
```

```
CALL das8(md%, VARPTR(d%), fl%)
```

```
md% = 1
```

```
LT%(0) = 0
```

```
LT%(1) = 0
```

```
fl% = 0
```

```
CALL das8(md%, VARPTR(LT%(0)), fl%)
```

```
x(7) = 0
```

```
height = 12.47
```

```
Depth = 15 / 30.48
```

```
ti = 6
```

```
ring = 30
```

```
density = 4.2
```

```
densityw = 1
```

```
1
```

```
FOR i = 0 TO 30
```

```
    READ cellconst(i)
```

```
NEXT i
```

' Each time after calibration the 31 new cell constants have to be

' entered in DATA.

```
G | DATA 0.95,1,1.05,1.12,1,1.08,1.09,0.97,1.15,1.18,1.19,1.60,1.58,1.12,1.25
```

```
    | DATA 1.27,1.15,1.22,1.33,1.39,1.32,1.13,0.8,0.8,1,1.1,1.1,1,1.05,1.1,1.2
```

```
FOR j = 0 TO 30
```

```
    cellconst(j) = 1
```

```
NEXT j
```

2

LINE (360, 10)-(620, 270), 6, BF

LINE (392, 265)-(392, 275), 3

LINE (425, 10)-(425, 275), 3, , &HF0F0

LINE (457, 265)-(457, 275), 3

LINE (490, 10)-(490, 275), 3, , &HF0F0

LINE (522, 265)-(522, 275), 3

LINE (555, 10)-(555, 275), 3, , &HF0F0

LINE (587, 265)-(587, 275), 3

LINE (355, 32)-(365, 32), 3

LINE (355, 75)-(620, 75), 3, , &HF0F0

LINE (355, 107)-(365, 107), 3

LINE (355, 140)-(620, 140), 3, , &HF0F0

LINE (355, 172)-(365, 172), 3

LINE (355, 205)-(620, 205), 3, , &HF0F0

LINE (355, 237)-(365, 237), 3

LINE (360, (1 - height / 16) \* 260 + 10)-(620, (1 - height / 16) \* 260 + 10), 12

LOCATE 23, 57

PRINT "% Solids"

LOCATE 3, 40

PRINT "H"

LOCATE 4, 40

PRINT "E"

LOCATE 5, 40

PRINT "I"

LOCATE 6, 40

PRINT "G"

LOCATE 7, 40

```
PRINT "H"  
LOCATE 8, 40  
PRINT "T"  
LOCATE 21, 46  
PRINT "0    20    40    60    80"  
LOCATE 1, 43  
PRINT "16"  
LOCATE 6, 43  
PRINT "12"  
LOCATE 11, 44  
PRINT "8"  
LOCATE 15, 44  
PRINT "4"  
LOCATE 20, 44  
PRINT "0"
```

```
LOCATE 1, 10  
PRINT "LOAD"  
LOCATE 1, 27  
PRINT "INTERFACE"  
LOCATE 2, 1  
PRINT "Press W-EEK"  
LOCATE 3, 1  
PRINT "Week Avg:"  
LOCATE 5, 1  
PRINT "Press D-ay"  
LOCATE 6, 1
```

```
PRINT "Day Avg: "  
LOCATE 8, 1  
PRINT "Press C-urrent"  
LOCATE 9, 1  
PRINT "Current:"  
LOCATE 16, 1  
PRINT "L"  
LOCATE 17, 1  
PRINT "O"  
LOCATE 18, 1  
PRINT "A"  
LOCATE 19, 1  
PRINT "D"  
LOCATE 13, 6  
PRINT "Time (Days Hrs)"  
LINE (110, 95)-(110, 102), 1  
LOCATE 14, 2  
PRINT "2500"  
LOCATE 18, 2  
PRINT "1250"  
LOCATE 22, 4  
PRINT "0"  
LOCATE 14, 42  
PRINT "1"  
LOCATE 18, 42  
PRINT ".5"  
LOCATE 22, 42  
PRINT "0"
```

```
LOCATE 23, 6
PRINT " 1 2 3 4 5 6 7 0 6 12 18 24"
LINE (45, 187)-(325, 302), 8, BF
LINE (61, 187)-(61, 302), 3, , &HF0F0
LINE (86, 187)-(86, 302), 3, , &HF0F0
LINE (111, 187)-(111, 302), 3, , &HF0F0
LINE (136, 187)-(136, 302), 3, , &HF0F0
LINE (161, 187)-(161, 302), 3, , &HF0F0
LINE (186, 187)-(186, 302), 3, , &HF0F0
LINE (211, 187)-(211, 302), 15
LINE (235, 187)-(235, 302), 3, , &HF0F0
LINE (263, 187)-(263, 302), 3, , &HF0F0
LINE (295, 187)-(295, 302), 3, , &HF0F0
flg = 1
```

9

```
ON ERROR GOTO 9.5
```

```
B | DATAS$ = "c:\inco\in" + LEFT$(DATES$, 2) + MIDS$(DATES$, 4, 2) + ".dat"
    | OPEN DATAS$ FOR APPEND AS #1
    | PRINT #1, "Date: ", DATES$
    | PRINT #1, "Time: ", TIMES$

    | PRINT #1, " "
    | CLOSE #1

    | NT$ = MIDS$(DATES$, 4, 2)
```

```
ringspace = 10 / 30.48
```

```
GOTO 10
```

```
9.5
```

```
errorcode$ = "99"
```

```
IF flgsav = 0 THEN
```

```
    GOSUB 999
```

```
    flgsav = 1
```

```
END IF
```

```
10
```

```
total = 0
```

```
water = 0
```

```
'IF ring < 20 THEN
```

```
    ' b = ring
```

```
    ' a = b - 5
```

```
'ELSE
```

```
    ' b = 20
```

```
    ' a = 15
```

```
'END IF
```

```
'IF a < 0 THEN a = 0
```

```
FOR S = 10 TO 12
```

```
    y = S + 1
```

```
    IF (S < 8) THEN
```

```
        OUT (&H100), (2 ^ S)
```

```
    END IF
```



```
IF (S > 7) AND (S < 16) THEN
    OUT (&H101), (2 ^ (S - 8))
END IF
```

```
IF (S > 15) AND (S < 24) THEN
    OUT (&H102), (2 ^ (S - 16))
END IF
```

```
IF (S > 23) AND (S < 32) THEN
    OUT (&H103), (2 ^ (S - 24))
END IF
```

```
IF (y < 8) THEN
    IF S > 8 THEN
        OUT (&H100), (2 ^ (y))
    ELSE
        OUT (&H100), (2 ^ (y) + 2 ^ (S))
    END IF
END IF
```

```
IF (y > 7) AND (y < 16) THEN
    IF (S < 8) OR (S > 15) THEN
        OUT (&H101), (2 ^ (y - 8))
    ELSE
        OUT (&H101), (2 ^ (y - 8) + (2 ^ (S - 8)))
    END IF
END IF
```

```
IF (y > 15) AND (y < 24) THEN
  IF (S < 16) OR (S > 23) THEN
    OUT (&H102), (2 ^ (y - 16))
  ELSE
    OUT (&H102), (2 ^ (y - 16) + 2 ^ (S - 16))
  END IF
END IF
```

```
IF (y > 23) AND (y < 32) THEN
  IF (S < 24) OR (S > 31) THEN
    OUT (&H103), (2 ^ (y - 24))
  ELSE
    OUT (&H103), (2 ^ (y - 24) + 2 ^ (S - 24))
  END IF
```

```
END IF
```

```
CALL delay(ti)
```

```
sig = 0
```

```
C | FOR z = 1 TO 25
```

```
md% = 4
```

```
d% = 0
```

```
fl% = 0
```

```
CALL das8(md%, VARPTR(d%), fl%)
```

```
sig = sig + d%
```

```
NEXT z
```

```
C | d% = sig / 25
```

```
F      K = (d% ^ 3) * 6.0636E-11 + (d% ^ 2) * 8.42806E-08 + d% * .012095 -  
      9.675  
      K = 1000 / K  
      K = K - 3.927  
      K = 1000 / K  
      cond(S) = K  
20    cond(S) = cond(S) / cellconst(S)  
      K$ = INKEY$  
      IF K$ = "c" OR K$ = "C" THEN  
          GOSUB 500  
      END IF  
      IF K$ = "D" OR K$ = "d" THEN  
          GOSUB 600  
      END IF  
      IF K$ = "W" OR K$ = "w" THEN  
          GOSUB 700  
      END IF  
      IF K$ = "X" OR K$ = "x" THEN  
          GOTO 399  
      END IF  
  
      IF (d% > 10) AND (d% < 4095) THEN  
          total = total + cond(S)  
          water = water + 1  
      END IF  
      FOR q = 0 TO 3
```

```
        OUT (&H100 + q), 0
    NEXT q

NEXT S
numer = 0
IF water = 0 OR water = 1 THEN
    water = 2
END IF

averl = total / water
FOR j = A TO b
    numer = numer + (averl - cond(j)) ^ 2
NEXT j
Lstd = (numer / (water - 1)) ^ .5
Sstd = Lstd

K$ = ""

FOR g = 0 TO 30
    S = g
    'IF s > 30 THEN
    '    s = (g - 16) * 2 + 1
    'END IF
    y = S + 1

    IF (S < 8) THEN
        OUT (&H100), (2 ^ S)
    END IF
```

```
IF (S > 7) AND (S < 16) THEN  
    OUT (&H101), (2 ^ (S - 8))  
END IF
```

```
IF (S > 15) AND (S < 24) THEN  
    OUT (&H102), (2 ^ (S - 16))  
END IF
```

```
IF (S > 23) AND (S < 32) THEN  
    OUT (&H103), (2 ^ (S - 24))  
END IF
```

```
IF (y < 8) THEN  
    IF S > 8 THEN  
        OUT (&H100), (2 ^ (y))  
    ELSE  
        OUT (&H100), (2 ^ (y) + 2 ^ (S))  
    END IF  
END IF
```

```
IF (y > 7) AND (y < 16) THEN  
    IF (S < 8) OR (S > 15) THEN  
        OUT (&H101), (2 ^ (y - 8))  
    ELSE  
        OUT (&H101), (2 ^ (y - 8) + (2 ^ (S - 8)))  
    END IF  
END IF
```

```
IF (y > 15) AND (y < 24) THEN
  IF (S < 16) OR (S > 23) THEN
    OUT (&H102), (2 ^ (y - 16))
  ELSE
    OUT (&H102), (2 ^ (y - 16) + 2 ^ (S - 16))
  END IF
END IF
IF (y > 23) AND (y < 32) THEN
  IF (S < 24) OR (S > 31) THEN
    OUT (&H103), (2 ^ (y - 24))
  ELSE
    OUT (&H103), (2 ^ (y - 24) + 2 ^ (S - 24))
  END IF
END IF
```

```
CALL delay(ti)
```

```
sig = 0
```

```
C | FOR z = 1 TO 25
    md% = 4
    d% = 0
    fl% = 0
    CALL das8(md%, VARPTR(d%), fl%)
    sig = sig + d%
NEXT z
```

```
C | d% = sig / 25
LOCATE 2, 55
PRINT " ";
```

```
LOCATE 2, 55
PRINT USING "Cell ##: DIG: #####"; y, d%

IF (d% < 20) OR (d% > 4094) THEN
    cond(S) = averl
    errorcode$ = "Bad Ring" + STR$(S) + " " + STR$(d%)
D | IF flgbr(S) = 0 THEN
    GOSUB 999
    flgbr(S) = 1
    END IF

    END IF

F | K = d% ^ 3 * 6.0636E-11 + d% ^ 2 * 8.42806E-08 + d% * .012095
    - 9.675
    K = 1000 / K
    K = K - 3.927
    K = 1000 / K
    cond(S) = K
    nochange(S) = K
30   cond(S) = cond(S) / cellconst(S)

LOCATE 3, 55
PRINT " ";
LOCATE 3, 55
PRINT USING "Cond.: ##.##"; cond(S)

IF averl = 0 THEN
```

```

        aver1 = cond(10)
    END IF
    IF g > 9 THEN
        aver12 = (cond(10) + cond(11) + cond(12)) / 3
        IF (ABS(aver1 - aver12) > .3) THEN
            aver1 = aver12
        END IF
    END IF
    solidsv(S) = (1 - cond(S) / aver1) / (1 + .5 * cond(S) / aver1)
    solids(S) = solidsv(S) * density / (solidsv(S) * density + densityw *
(1 - solidsv(S)))
    IF solids(S) < 0 THEN
        solids(S) = 0
    END IF
    IF solids(S) > .8 THEN
        solids(S) = .8
    END IF
    solids(S) = solids(S) * 100
    LOCATE 4, 55
    PRINT "          ";
    LOCATE 4, 55
    PRINT USING "Solids (%): ###.##"; solids(S)

    profweek(S) = profweek(S) + solids(S)
    profday(S) = profday(S) + solids(S)
    K$ = INKEY$
    IF K$ = "c" OR K$ = "C" THEN
        GOSUB 500

```



```
        END IF
        IF K$ = "D" OR K$ = "d" THEN
            GOSUB 600
        END IF
        IF K$ = "W" OR K$ = "w" THEN
            GOSUB 700
        END IF
        IF K$ = "X" OR K$ = "x" THEN
            GOTO 399
        END IF

        FOR q = 0 TO 3
            OUT (&H100 + q), 0
        NEXT q

    NEXT g

    IF flg = 1 THEN
        LINE (360, 10)-(620, 270), 6, BF
        LINE (392, 265)-(392, 275), 3
        LINE (425, 10)-(425, 275), 3, , &HF0F0
        LINE (457, 265)-(457, 275), 3
        LINE (490, 10)-(490, 275), 3, , &HF0F0
        LINE (522, 265)-(522, 275), 3
        LINE (555, 10)-(555, 275), 3, , &HF0F0
        LINE (587, 265)-(587, 275), 3
        LINE (355, 32)-(365, 32), 3
        LINE (355, 75)-(620, 75), 3, , &HF0F0
```

```
LINE (355, 107)-(365, 107), 3
LINE (355, 140)-(620, 140), 3, , &HF0F0
LINE (355, 172)-(365, 172), 3
LINE (355, 205)-(620, 205), 3, , &HF0F0
LINE (355, 237)-(365, 237), 3
LINE (360, (1 - height / 16) * 260 + 10)-(620, (1 - height / 16) * 260 + 10), 12
END IF
```

```
FOR j = 0 TO 29
  IF solids(j) < 0 THEN solids(j) = 0
  IF solidsv(j) < 0 THEN solidsv(j) = 0
  corrsolids(j) = solids(j)
  FOR K = j TO 30
    IF solids(j) > solids(K) AND solids(K) < 10 THEN
      corrsolids(j) = 0
      solidsv(j) = 0
    END IF
  NEXT K
NEXT j
corrsolids(30) = solids(30)
FOR S = 0 TO 30
  IF flg = 1 THEN
    y = S + 1
    IF S = 0 THEN
      X1 = (corrsolids(S) / 80 * 260 + 360)
      y1 = (1 - height / 16) * 260 + 10
    END IF
```

```
x2 = (corrsolids(S) / 80 * 260 + 360)
y2 = ((16 - height) + Depth + ringspace * y) / 16 * 260 + 10
LINE (X1, y1)-(x2, y2), 14
X1 = x2
y1 = y2

      END IF
NEXT S
50
LSinterface = height
SSinterface = height
ring = 27
cond(31) = 0
cond(32) = 0
cond(33) = 0

FOR j = 2 TO 30
  x = 30 - j
  IF (solids(x) < 10) AND (solids(x - 1) < 10) AND (solids(x - 2) < 10)
  THEN
    LSinterface = (x + .5) * ringspace + Depth
    ring = x
    GOTO 100
  END IF
NEXT j
100
FOR j = (ring + 1) TO 30
  Sstd = .2
```

```
        IF (ABS(cond(j) - cond(j + 1)) < (2 * Sstd)) AND (ABS(cond(j) - cond(j
+ 2)) < 2 * Sstd)
        AND (ABS(cond(j) - cond(j + 3)) < 2 * Sstd) THEN
            SSinterface = (j + .5) * ringspace + Depth
            GOTO 200
        END IF
    NEXT j
200
LOAD = 0
FOR j = 0 TO 29
    LOAD = LOAD + solidsv(j) * 88.289 * 4.2 / .9072
NEXT j
LOAD = LOAD + solidsv(30) * 484.47 * 4.2 / .9072

INTERFACE = 0
LIQ = 0
SOL = 0
MUD = 0
FOR j = 10 TO 17
    LIQ = LIQ + cond(j)
NEXT j
LIQ = LIQ / 8
FOR j = 18 TO 27
    SOL = SOL + cond(j)
NEXT j
SOL = SOL / 10
FOR j = 28 TO 30
    MUD = MUD + cond(j)
```

```
NEXT j
MUD = MUD / 3

INTERFACE = (LIQ - SOL) / (LIQ - MUD)

LOCATE 9, 10
LSinterface = height - LSinterface
SSinterface = height - SSinterface

PRINT USING "#####"; LOAD
LOCATE 9, 27
PRINT USING ".###"; INTERFACE

x(7) = x(7) + 1
daytot = daytot + LOAD
daytot2 = daytot2 + INTERFACE
dayavg = daytot / x(7)
dayavg2 = daytot2 / x(7)
histweek(tot + x(7)) = LOAD
histweek2(tot + x(7)) = INTERFACE
weektot = 0
weektot2 = 0
FOR j = 1 TO (tot + x(7))
    weektot = weektot + histweek(j)
    weektot2 = weektot2 + histweek2(j)
NEXT j
weekavg = weektot / (tot + x(7))
weekavg2 = weektot2 / (tot + x(7))
```

```
LOCATE 3, 10
PRINT USING "#####"; weekavg
LOCATE 3, 27
PRINT USING ".###"; weekavg2
LOCATE 6, 10
A PRINT USING "#####"; dayavg
LOCATE 6, 27
PRINT USING ".###"; dayavg2
MUDLINE = SSinterface
sedimentline = LSinterface
LINE (360, (1 - SSinterface / 16) * 260 + 10)-(620, (1 - SSinterface / 16) * 260
+ 10), 14
LINE (360, (1 - LSinterface / 16) * 260 + 10)-(620, (1 - LSinterface / 16) * 260
+ 10), 14, , &HF0F0

OPEN DATAS$ FOR APPEND AS #1
PRINT #1, TIMES$,
FOR S = 0 TO 30
    PRINT #1, nochange(S),
NEXT S
PRINT #1, LSinterface, SSinterface, LOAD, INTERFACE
CLOSE #1

IF LOAD < 0 THEN
    LOAD = 0
END IF
E IF LOAD > 2500 THEN
    LOAD = 2500
```

```
END IF
IF INTERFACE < 0 THEN
    INTERFACE = 0
END IF

IF INTERFACE > 1 THEN
    INTERFACE = 1
END IF

IF VAL(LEFT$(TIMES$, 2)) = 0 THEN GOTO 209
IF x(7) = 1 THEN
209  star = VAL(LEFT$(TIMES$, 2)) * 60 + VAL(MID$(TIMES$, 4, 2))
    x3 = star / 1440 * 114 + 211
    y3 = (2500 - LOAD) / 2500 * 115 + 187
    LINE (x3, y3)-(x3, y3), 15
ELSE
    cont = VAL(LEFT$(TIMES$, 2)) * 60 + VAL(MID$(TIMES$, 4, 2))
    x4 = cont / 1440 * 114 + 211
    y4 = (2500 - LOAD) / 2500 * 115 + 187
    LINE (x3, y3)-(x4, y4), 15
    x3 = x4
    y3 = y4
END IF
IF VAL(LEFT$(TIMES$, 2)) = 0 THEN GOTO 209.5
IF x(7) = 1 THEN
209.5  star = VAL(LEFT$(TIMES$, 2)) * 60 + VAL(MID$(TIMES$, 4, 2))
    x3 = star / 1440 * 114 + 211
    y3 = (1 - INTERFACE) * 115 + 187
```

```
LINE (x3, y3)-(x3, y3), 13
ELSE
  cont = VAL(LEFT$(TIMES, 2)) * 60 + VAL(MID$(TIMES, 4, 2))
  x4 = cont / 1440 * 114 + 211
  y4 = (1 - INTERFACE) * 115 + 187

  LINE (x3, y3)-(x4, y4), 13
  x3 = x4
  y3 = y4
END IF
```

```
E | IF LOAD > 2500 THEN LOADOUT = 4095
  IF INTERFACE > 1 THEN INTOUT = 4095
  LOADOUT = INT(LOAD / 2500 * 4095)
  INTOUT = INT(INTERFACE * 4095)
  md% = 23
  d%(0) = 0
  d%(1) = LOADOUT
  fl% = 0
  CALL das8(md%, VARPTR(d%(0)), fl%)
  md% = 23
  d%(0) = 1
  d%(1) = INTOUT
  fl% = 0
  CALL das8(md%, VARPTR(d%(0)), fl%)
```

'c = 15

'208



```
'IF (cond(c) > 45) OR (cond(c) < 15) THEN
```

```
'    c = c - 1
```

```
'    GOTO 208
```

```
'END IF
```

```
'a = 20
```

```
'IF ring < 20 THEN a = ring - 1
```

```
'FOR j = 3 TO a
```

```
'    cellconst(j) = cond(15) / cond(j)
```

```
'NEXT j
```

```
210
```

```
S = 1: y = 2
```

```
OUT (&H100), (2 ^ (y) + 2 ^ (S))
```

```
CALL delay(ti)
```

```
sig = 0
```

```
C | FOR z = 1 TO 25
```

```
    md% = 4
```

```
    d% = 0
```

```
    fl% = 0
```

```
    CALL das8(md%, VARPTR(d%), fl%)
```

```
    sig = sig + d%
```

```
NEXT z
```

```
C | d% = sig / 25
```

```
oldad1 = d%
```

```
newad1 = d%
```

```
S = 4: y = 5
OUT (&H100), (2 ^ (y) + 2 ^ (S))
CALL delay(ti)
```

```
sig = 0
```

```
C | FOR z = 1 TO 25
    md% = 4
    d% = 0
    fl% = 0
    CALL das8(md%, VARPTR(d%), fl%)
    sig = sig + d%
NEXT z
```

```
C | d% = sig / 25
    oldad2 = d%
    newad2 = d%
    counter = 0
    newad3 = 1000
    newad4 = 1000
```

```
WHILE (oldad1 / newad1 < 1.15) OR (oldad2 / newad2 < 1.15)
```

```
S = 1: y = 2
OUT (&H100), (2 ^ (y) + 2 ^ (S))
CALL delay(ti)
```

```
sig = 0
```

```
C | FOR z = 1 TO 25
    md% = 4
```

```
        d% = 0
        fl% = 0
        CALL das8(md%, VARPTR(d%), fl%)
        sig = sig + d%
    NEXT z
C | d% = sig / 25
    newad1 = d%

    S = 4: y = 5
    OUT (&H100), (2 ^ (y) + 2 ^ (S))
    CALL delay(ti)
    sig = 0
C | FOR z = 1 TO 25
    md% = 4
    d% = 0
    fl% = 0
    CALL das8(md%, VARPTR(d%), fl%)
    sig = sig + d%
NEXT z
C | d% = sig / 25
    newad2 = d%
    OUT (&H100), (2 ^ 6 + 2 ^ 7)
    CALL delay(ti)
    md% = 4
    d% = 0
    fl% = 0
    CALL das8(md%, VARPTR(d%), fl%)
```

```
newad3 = d%
```

```
OUT (&H100), (2 ^ 3 + 2 ^ 4)
```

```
CALL delay(ti)
```

```
md% = 4
```

```
d% = 0
```

```
fl% = 0
```

```
CALL das8(md%, VARPTR(d%), fl%)
```

```
newad4 = d%
```

```
K$ = INKEY$
```

```
IF K$ = "c" OR K$ = "C" THEN
```

```
    S = 31
```

```
    GOSUB 500
```

```
END IF
```

```
IF K$ = "D" OR K$ = "d" THEN
```

```
    GOSUB 600
```

```
END IF
```

```
IF K$ = "W" OR K$ = "w" THEN
```

```
    GOSUB 700
```

```
END IF
```

```
IF K$ = "x" OR K$ = "X" THEN
```

```
    GOTO 399
```

```
END IF
```

```
counter = counter + 1
```

```
IF counter > 100 THEN
```

```
    IF flgsp = 0 THEN
```

```
        '      errorcode$ = "101"
        '      GOSUB 999
        '      flgsp = 1
        GOTO 220
    ELSE
        GOTO 220
    END IF
END IF
WEND

CALL delay(60)

220
IF NT$ = MID$(DATE$, 4, 2) THEN GOTO 10

300
tot = x(1) + x(2) + x(3) + x(4) + x(5) + x(6) + x(7)
GOSUB 400
FOR j = 1 TO tot
    histweek(j) = histweek(j + x(1))
    histweek2(j) = histweek2(j + x(1))
NEXT j
FOR j = 1 TO 22
    profweek(j) = profweek(j) - x(1) * profweek(j) / tot
    profday(j) = 0
NEXT j
weektot = weektot - x(1) * weekavg
weektot2 = weektot2 - x(1) * weekavg2
```

daytot = 0

daytot2 = 0

x(1) = x(2)

x(2) = x(3)

x(3) = x(4)

x(4) = x(5)

x(5) = x(6)

x(6) = x(7)

x(7) = 0

tot = x(1) + x(2) + x(3) + x(4) + x(5) + x(6) + x(7)

GOTO 9

399

END

400

LINE (45, 187)-(325, 302), 8, BF

LINE (61, 187)-(61, 302), 3, , &HF0F0

LINE (86, 187)-(86, 302), 3, , &HF0F0

LINE (111, 187)-(111, 302), 3, , &HF0F0

LINE (136, 187)-(136, 302), 3, , &HF0F0

LINE (161, 187)-(161, 302), 3, , &HF0F0

LINE (186, 187)-(186, 302), 3, , &HF0F0

LINE (211, 187)-(211, 302), 15

LINE (235, 187)-(235, 302), 3, , &HF0F0

LINE (263, 187)-(263, 302), 3, , &HF0F0

LINE (295, 187)-(295, 302), 3, , &HF0F0

```
st = 211
FOR j = 1 TO 7
  IF x(j) > 0 THEN
    st = st - 166 / 7
  END IF
NEXT j

FOR j = 1 TO tot
  range = 211 - st
  IF histweek(j) < 2.5 THEN
    histweek(j) = 2.5
  END IF
  IF histweek(j) > 12.5 THEN
    histweek(j) = 12.5
  END IF
  IF j = 1 THEN
    x5 = st
    y5 = (12.5 - histweek(j)) / 10 * 115 + 187
    LINE (x5, y5)-(x5, y5), 15
  ELSE
    x6 = j * range / tot + st
    y6 = (12.5 - histweek(j)) / 10 * 115 + 187
    LINE (x5, y5)-(x6, y6), 15
    x5 = x6
    y5 = y6
  END IF
NEXT j
FOR j = 1 TO tot
```

```
range = 211 - st
IF histweek2(j) < 2.5 THEN
    histweek2(j) = 2.5
END IF
IF histweek2(j) > 12.5 THEN
    histweek2(j) = 12.5
END IF
IF j = 1 THEN
    x5 = st
    y5 = (12.5 - histweek2(j)) / 10 * 115 + 187
    LINE (x5, y5)-(x5, y5), 7
ELSE
    x6 = j * range / tot + st
    y6 = (12.5 - histweek2(j)) / 10 * 115 + 187
    LINE (x5, y5)-(x6, y6), 7
    x5 = x6
    y5 = y6
END IF
NEXT j

RETURN

500
LINE (360, 10)-(620, 270), 6, BF
LINE (392, 265)-(392, 275), 3
LINE (425, 10)-(425, 275), 3, , &HF0F0
LINE (457, 265)-(457, 275), 3
LINE (490, 10)-(490, 275), 3, , &HF0F0
```



```
LINE (522, 265)-(522, 275), 3
LINE (555, 10)-(555, 275), 3, , &HF0F0
LINE (587, 265)-(587, 275), 3
LINE (355, 32)-(365, 32), 3
LINE (355, 75)-(620, 75), 3, , &HF0F0
LINE (355, 107)-(365, 107), 3
LINE (355, 140)-(620, 140), 3, , &HF0F0
LINE (355, 172)-(365, 172), 3
LINE (355, 205)-(620, 205), 3, , &HF0F0
LINE (355, 237)-(365, 237), 3
LINE (360, (1 - height / 16) * 260 + 10)-(620, (1 - height / 16) * 260 + 10), 12
```

```
FOR K = 0 TO S
```

```
    j = K + 1
```

```
    IF K = 0 THEN
```

```
        X1 = 360
```

```
        y1 = 10 + (1 - height / 16) * 260
```

```
    END IF
```

```
        x2 = (solids(S) / 12 * 260 + 360)
```

```
        y2 = ((16 - height) + Depth + ringspace * j) / 16 * 260 + 10
```

```
        LINE (X1, y1)-(x2, y2), 14
```

```
        X1 = x2
```

```
        y1 = y2
```

```
NEXT K
```

```
flg = 1
```

```
K$ = " "
```

```
RETURN
```

```
600
LINE (360, 10)-(620, 270), 6, BF
LINE (392, 265)-(392, 275), 3
LINE (425, 10)-(425, 275), 3, , &HF0F0
LINE (457, 265)-(457, 275), 3
LINE (490, 10)-(490, 275), 3, , &HF0F0
LINE (522, 265)-(522, 275), 3
LINE (555, 10)-(555, 275), 3, , &HF0F0
LINE (587, 265)-(587, 275), 3
LINE (355, 32)-(365, 32), 3
LINE (355, 75)-(620, 75), 3, , &HF0F0
LINE (355, 107)-(365, 107), 3
LINE (355, 140)-(620, 140), 3, , &HF0F0
LINE (355, 172)-(365, 172), 3
LINE (355, 205)-(620, 205), 3, , &HF0F0
LINE (355, 237)-(365, 237), 3
LINE (360, (1 - height / 16) * 260 + 10)-(620, (1 - height / 16) * 260 + 10), 12
FOR j = 0 TO 30
    IF j < S THEN
        pt = x(7) + 1
    ELSE
        pt = x(7)
    END IF
    j = K + 1
    IF K = 1 THEN
        X1 = 360
        y1 = 10 + (1 - height / 16) * 260
    END IF
```

```
x2 = (profday(j) / pt / 80 * 260 + 360)
y2 = ((16 - height) + Depth + ringspace * j) / 16 * 260 + 10
LINE (X1, y1)-(x2, y2), 14
X1 = x2
y1 = y2
NEXT j

flg = 0
KS = " "
RETURN

700
LINE (360, 10)-(620, 270), 6, BF
LINE (392, 265)-(392, 275), 3
LINE (425, 10)-(425, 275), 3, , &HF0F0
LINE (457, 265)-(457, 275), 3
LINE (490, 10)-(490, 275), 3, , &HF0F0
LINE (522, 265)-(522, 275), 3
LINE (555, 10)-(555, 275), 3, , &HF0F0
LINE (587, 265)-(587, 275), 3
LINE (355, 32)-(365, 32), 3
LINE (355, 75)-(620, 75), 3, , &HF0F0
LINE (355, 107)-(365, 107), 3
LINE (355, 140)-(620, 140), 3, , &HF0F0
LINE (355, 172)-(365, 172), 3
LINE (355, 205)-(620, 205), 3, , &HF0F0
LINE (355, 237)-(365, 237), 3
LINE (360, (1 - height / 16) * 260 + 10)-(620, (1 - height / 16) * 260 + 10), 12
```

```
FOR j = 0 TO 30
  IF j < S THEN
    pt = tot + 1
  ELSE
    pt = tot
  END IF

  IF j = 1 THEN
    X1 = (profweek(j) / pt / 80 * 260 + 360)
    y1 = Depth / height * 260 + 10
    LINE (X1, y1)-(X1, y1), 14
  ELSE
    x2 = (profweek(j) / pt / 80 * 260 + 360)
    y2 = ((16 - height) + Depth + ringspace * (j + 1)) / 16 * 260 + 10
    LINE (X1, y1)-(x2, y2), 14
    X1 = x2
    y1 = y2
  END IF
NEXT j

flg = 0
K$ = " "
RETURN

999
md% = 23
d%(0) = 0
d%(1) = 4095
fl% = 0
```

```
CALL das8(md%, VARPTR(d%(2)), fl%)
```

```
md% = 23
```

```
d%(0) = 1
```

```
d%(1) = 4095
```

```
fl% = 0
```

```
CALL das8(md%, VARPTR(d%(2)), fl%)
```

```
LOCATE 13, 47
```

```
PRINT "Error "; errorcode$
```

```
LOCATE 14, 47
```

```
PRINT "Please call McGill!"
```

```
D LOCATE 15, 47
```

```
PRINT "Press 'A' to continue"
```

```
LOCATE 16, 47
```

```
PRINT "Err ="; ERR
```

```
999.2
```

```
IF INKEY$ = "a" OR INKEY$ = "A" THEN GOTO 999.5
```

```
GOTO 999.2
```

```
999.5
```

```
md% = 23
```

```
d%(0) = 0
```

```
d%(1) = slout
```

```
fl% = 0
```

```
CALL das8(md%, VARPTR(d%(2)), fl%)
```

```
md% = 23
```

```
d%(0) = 1
```

```
d%(1) = mlout
```

```
f% = 0
CALL das8(md%, VARPTR(d%(2)), f%)
RETURN

SUB delay (ti)
    t1 = TIMER + ti
    IF t1 > 86400 THEN

        t1 = t1 - 86400
999.9    IF TIMER < 80000 THEN
            GOTO 1000
        ELSE
            GOTO 999.9
        END IF
    END IF

1000    DO
        IF t1 - TIMER > 120 THEN GOTO 1001
    LOOP UNTIL TIMER >= t1

1001
END SUB
```

# APPENDIX B

## VISUAL BASIC PROGRAM FOR DATA ACQUISITION

In this appendix the main parts of the Visual Basic program are given.

The subroutines `Form_Load`, `Relay1` and `rel1_ProcessDone` are written to read the values of board a. In subroutine, `rel1_ProcessDone`, DAS-8 was called. The subroutine that controls the DAS-8 board and the handling of voltage to convert it to conductance, is done in the subroutines `Das8` and `SR_AI_ServiceDone`, respectively.

```
Sub Form_Load () ' when the program starts, this is the first function to run initialize
                  program variables
Dim i As Integer ' i is a counter in the loop to read the cell constants from a file
InitGlobalVars
c = 1            ' boolean value to tell board to start reading
a = 3           ' read cell 1 on board 1

Open "c:\constant\calib.ini" For Random As #1 Len = 8
For i = 1 To 16
    Get #1, i, rin(i)
```

Next i

Get #1, 20, t(0)

For i = 1 To 15

    Get #1, i + 20, t(I)

Next i

Close #1

cmdeditexesr.Enabled = False

'Saving of the data in the directory "data" with the month, day and time

    dia\$ = Date\$

    filn\$ = "c:\data\" + Mid\$(dia\$, 9, 2) + Left\$(dia\$, 2) + Mid\$(dia\$, 4, 2) + ".dat"

    fecha.Caption = dia\$

    hor\$ = Time\$

    hora.Caption = Time\$

    aux\_counter = 1

    hui = 1

    Rel1.DOScalar = a     ' rel1 to read cell 1

    Rel1.ArmState = 1     ' open board 1

    relay1 (a)

End Sub

---

Sub relay1 (Value As Long)

'this function to read from board 1

    form1.Rel1.DOScalar = Value



```

form1.Rel1.Refresh
form1.Rel1.ArmState = 1
End Sub

```

---

```

Sub rel1_ProcessDone (WarningCode As Integer)
    form1.Rel1.ArmState = 2
    Call waiting(5)
    If a <> 2 ^ 16 Then
        das8
    End If
End Sub

```

---

```

Sub das8 ()
    ReDim vbdataarray1(100)           '100 voltage measurements
    Dim j As Integer
    Dim in As Integer
    numsamples = 100
    SampleRate = 100
    'For in = 1 To 5
    init_device SR_AI
    form1.SR_AI.Req_op = dl_device
    form1.SR_AI.Req_device = 0
    SR_AI.Req_subsystem = dl_ai
    SR_AI.Req_mode = dl_polled
    SR_AI.Req_op = dl_start
    SR_AI.Refresh
    ' Call procedure to start data acquisition
    GetAnalogBuffer SR_AI, InputMode, AI_Channel, numsamples, SampleRate,

```

StopEventType

'GetAnalogBuffer SR\_AI, DL\_POLLED, AI\_Channel, 1, 10, StopEventType

dummy = VBAArrayBufferConvert(SR\_AI, 0, 0, numsamples, vbdataarray1(0), DL\_tsingle,  
0, 0)

'ADVALUE.Caption = Str\$(aux / 100)

'ADVALUE.Refresh

'Next in

'advalue.Text = Str\$(dlgain2volts(sr\_ai, 9, 1))

End Sub

---

Sub SR\_AI\_ServiceDone (task As Integer, device As Integer, subsystem As Integer, mode  
As Integer)

' if one cell is done 100 times, get the average.

Dim jo As Double ' sum of voltage for the for loop

Dim i As Integer ' for loop counter

Dim vo As Double ' average voltage output

jo = 0

For i = 1 To 100

jo = jo + vbdataarray1(i) 'vbdataarray comes from DAS8

Next i

vo = jo / 100

jo = Conductance(vo) ' jo becomes the conductance

'jo = 1000 / jo 'Subtraction of resistance of the rope

'jo = jo - 3.927

'jo = 1000 / jo

aux(aux\_counter) = jo ' Put conductance to corresponding element in

array, aux\_counter is the index of the array aux

k(aux\_counter) = get\_ko(aux\_counter) ' k is the conductivity obtained through multiplying

matrix, which is done in the function get\_ko = aux  
(conductance) \* cell constant

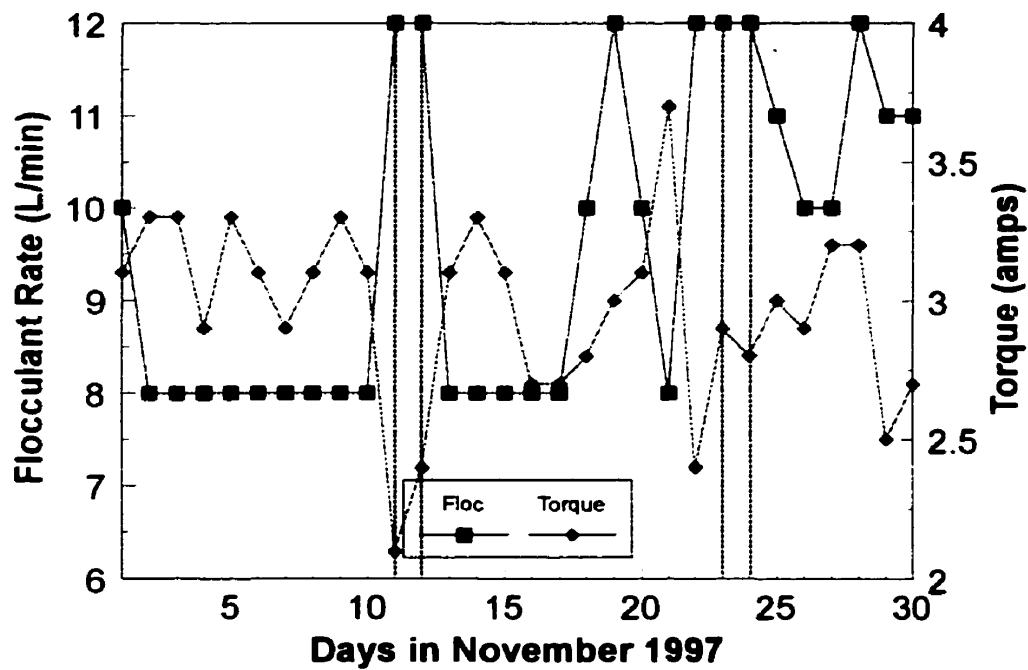
```
aux_counter = aux_counter + 1  
advalue1.Text = Str$(k(aux_counter - 1))  
advalue1.Refresh  
advalue1.ArmState = 1  
advalue2.Text = Str$(t(I))  
advalue2.Refresh  
advalue2.ArmState = 1  
End Sub
```

---

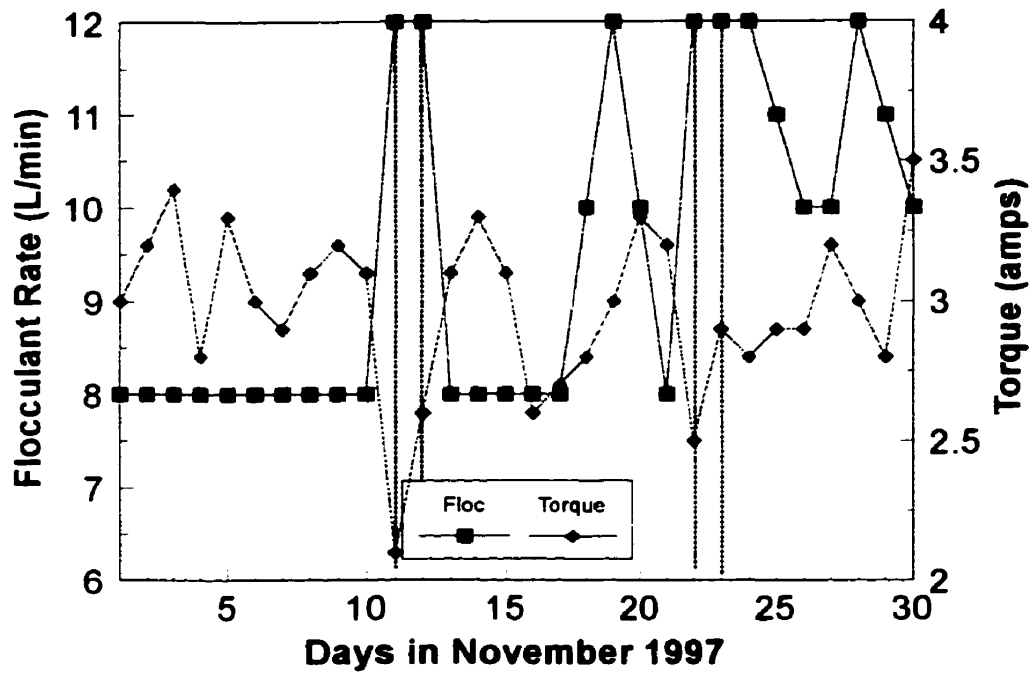
# APPENDIX C

## TORQUE AND FLOCCULANT RATE

Following is given the data of the torque and the flocculant rate from November 1997 until May 1998. The dotted vertical lines mean that on that day dirty overflow was reported.

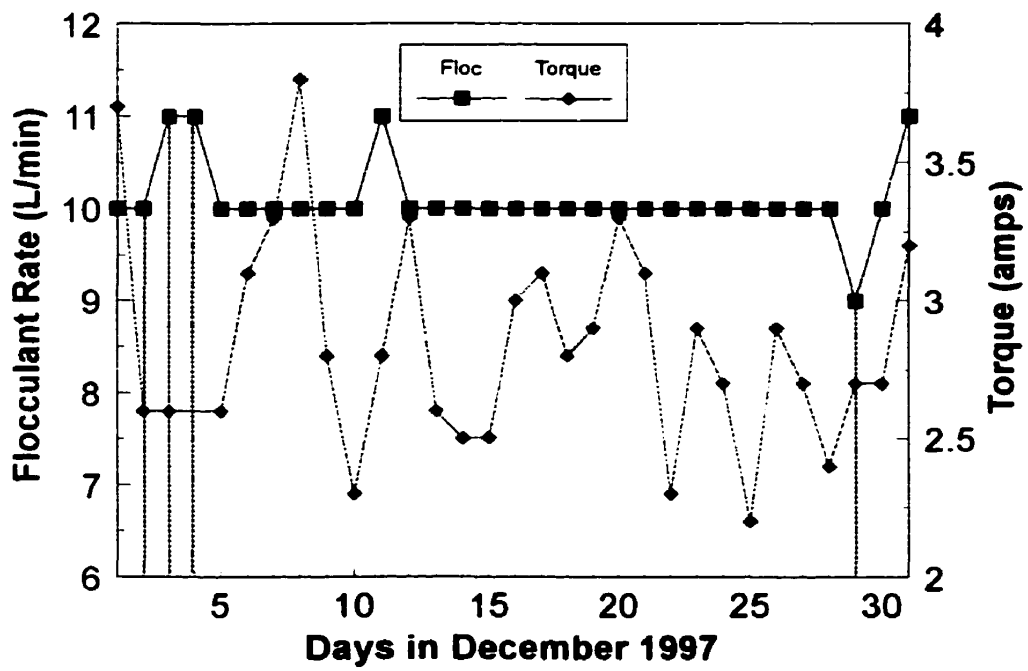


(a)

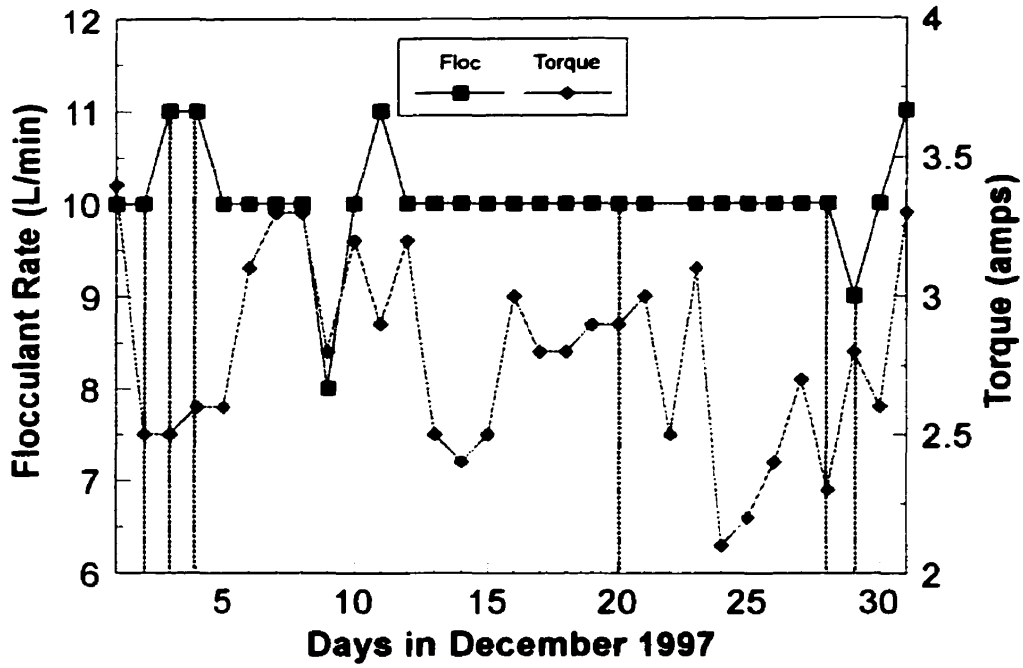


(b)

Figure C.1: Torque and flocculant rate for November 1997 at (a) 12 am and (b) 4 am.

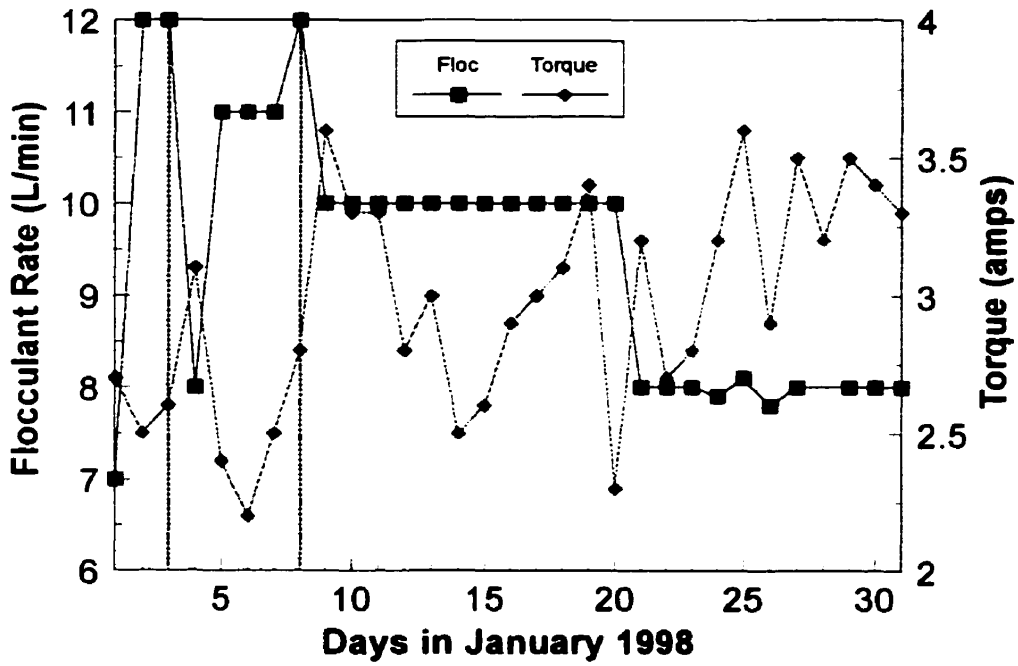


(a)

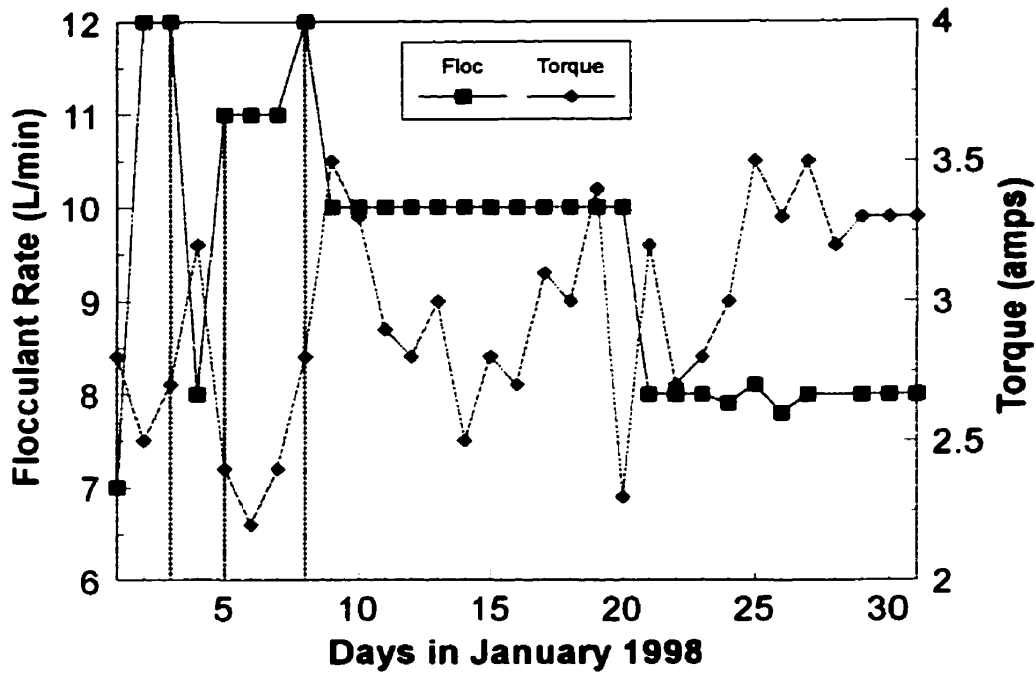


(b)

Figure C.2: Torque and flocculant rate for December 1997 at (a) 12 am and (b) 4 am.

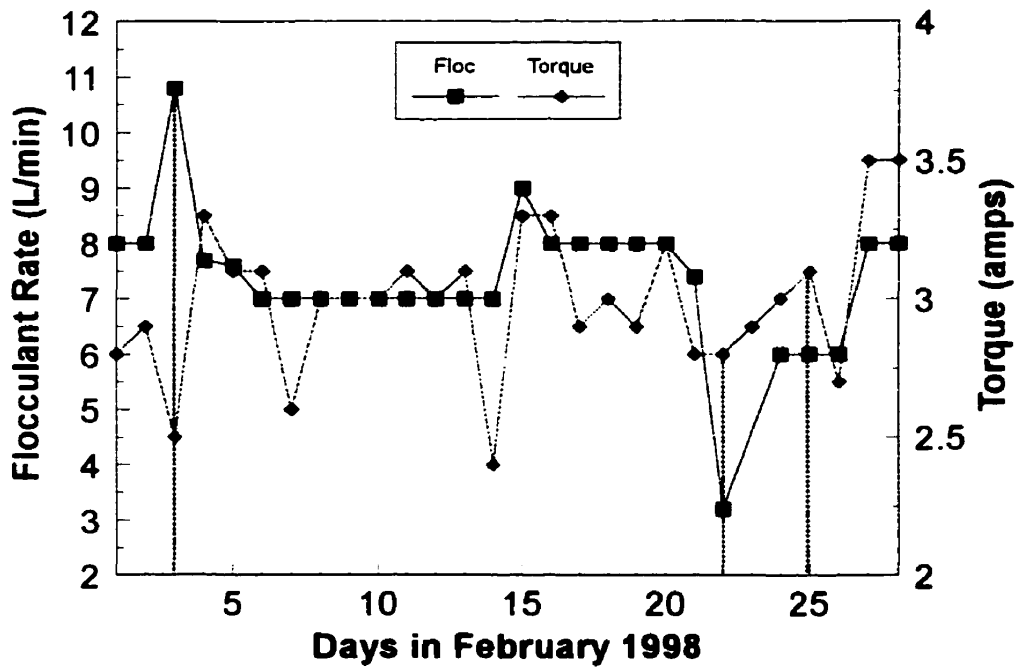


(a)

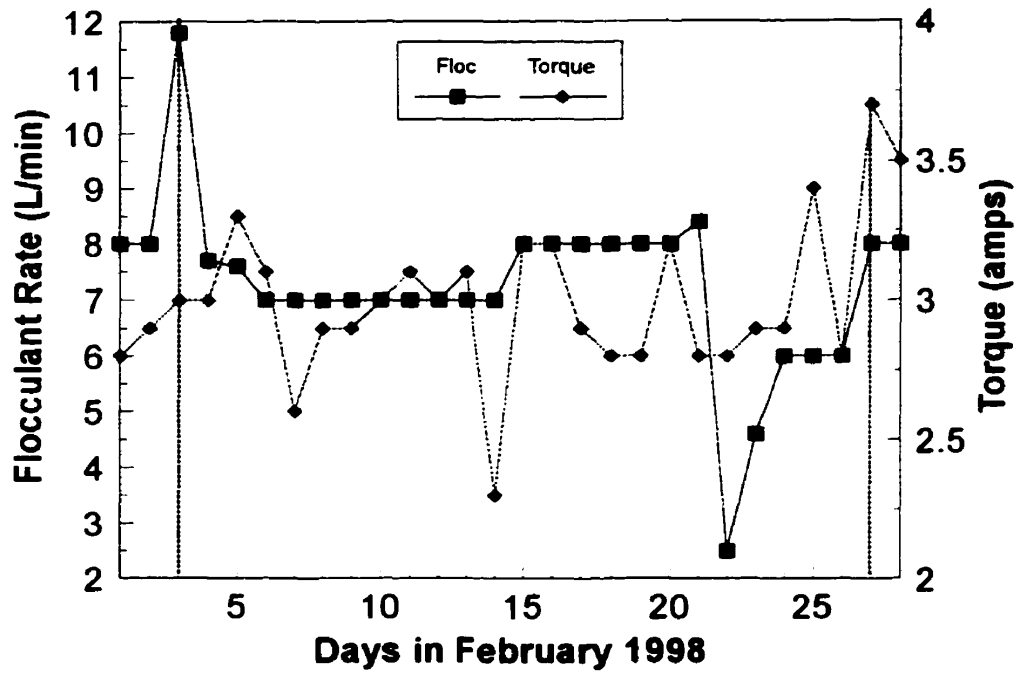


(b)

Figure C.3: Torque and flocculant rate for January 1998 at (a) 12 am and (b) 4 am.

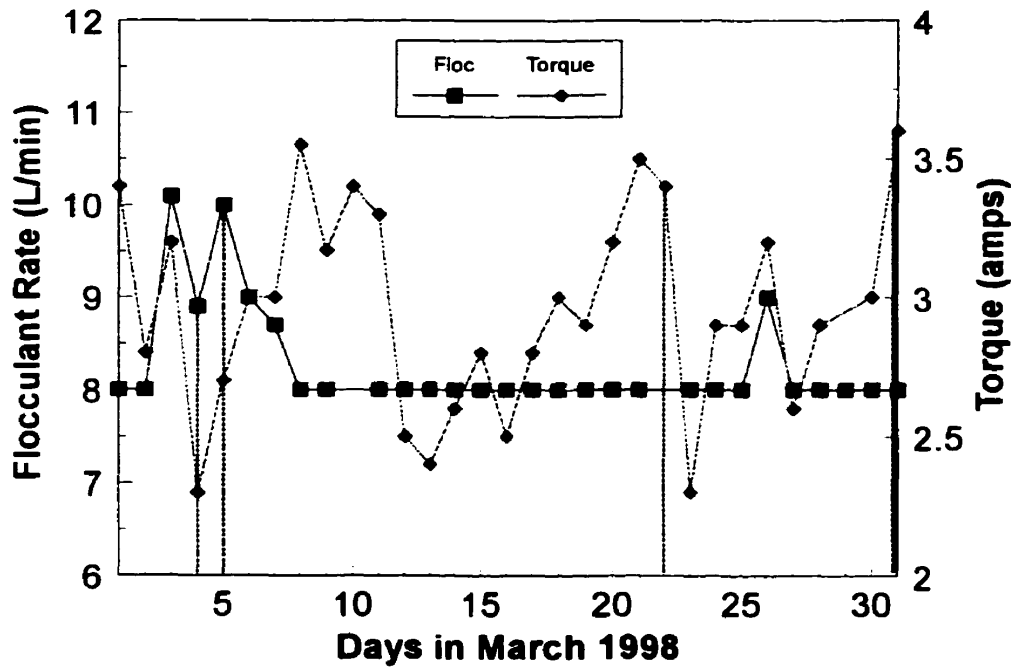


(a)



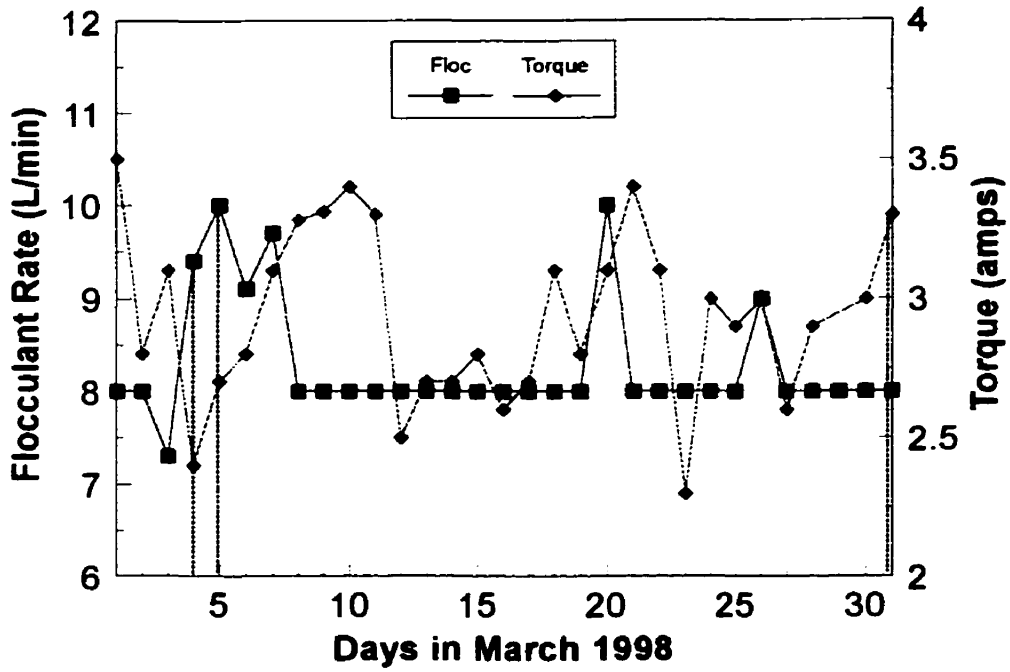
(b)

Figure C.4: Torque and flocculant rate for February 1998 at (a) 12 am and (b) 4 am.



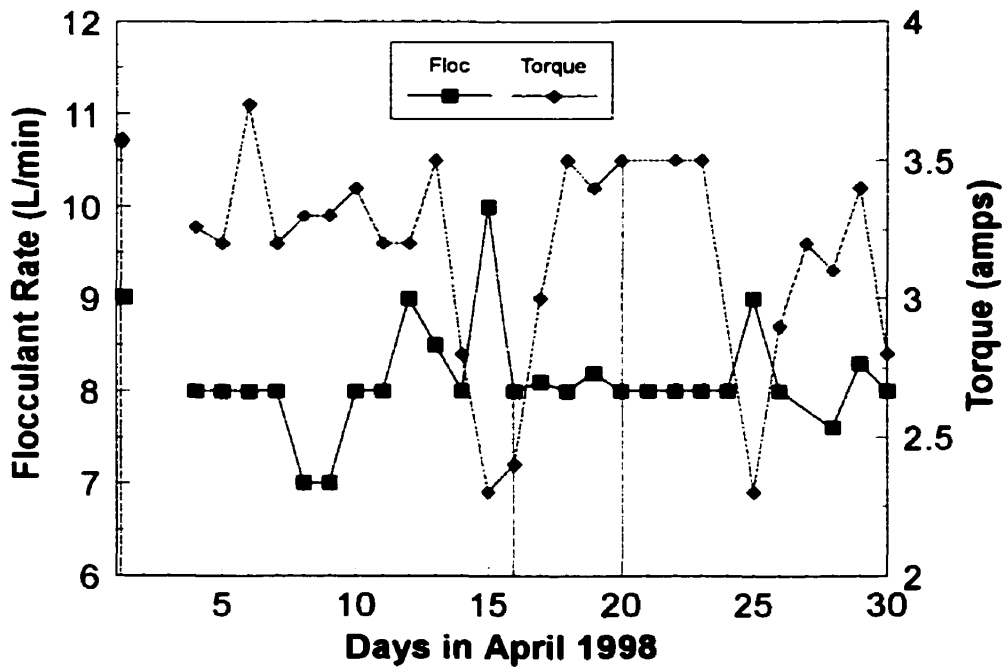
(a)



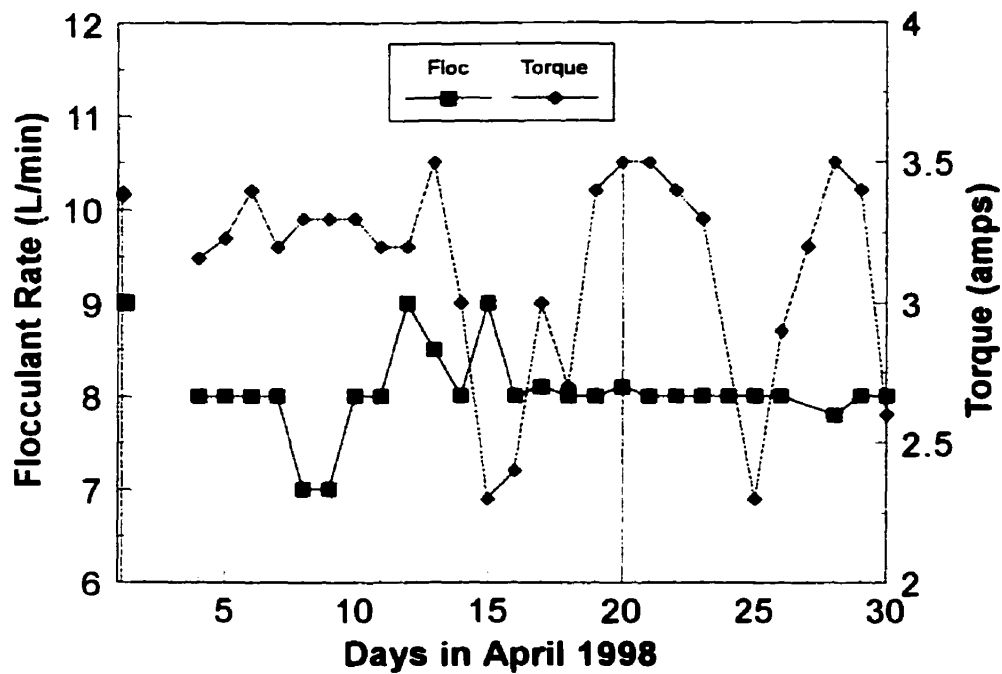


(b)

Figure C.5: Torque and flocculant rate for March 1998 at (a) 12 am and (b) 4 am.

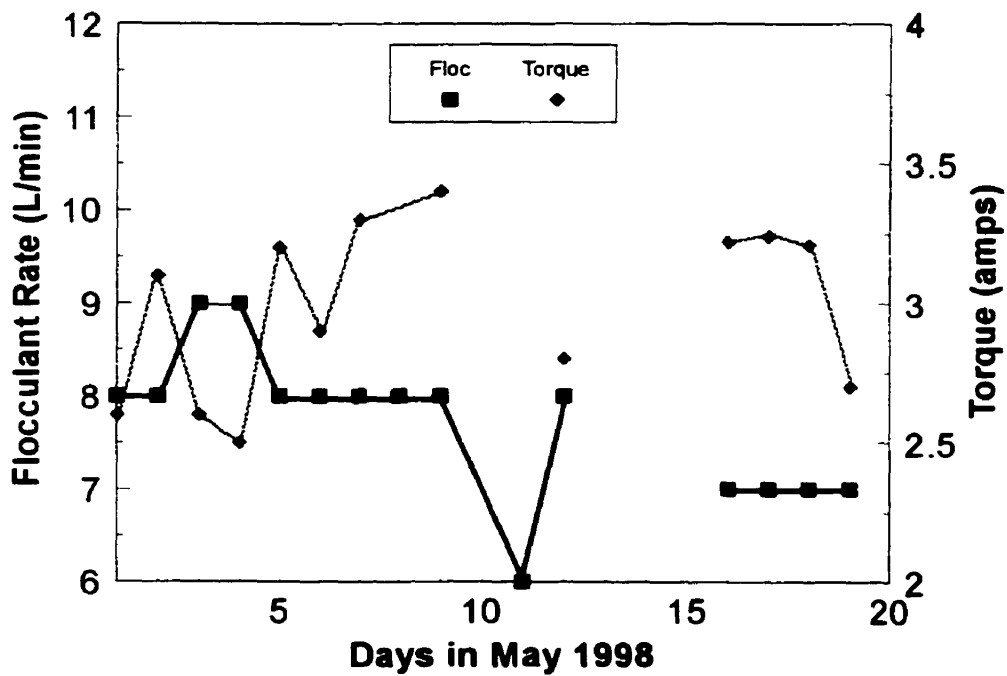


(a)

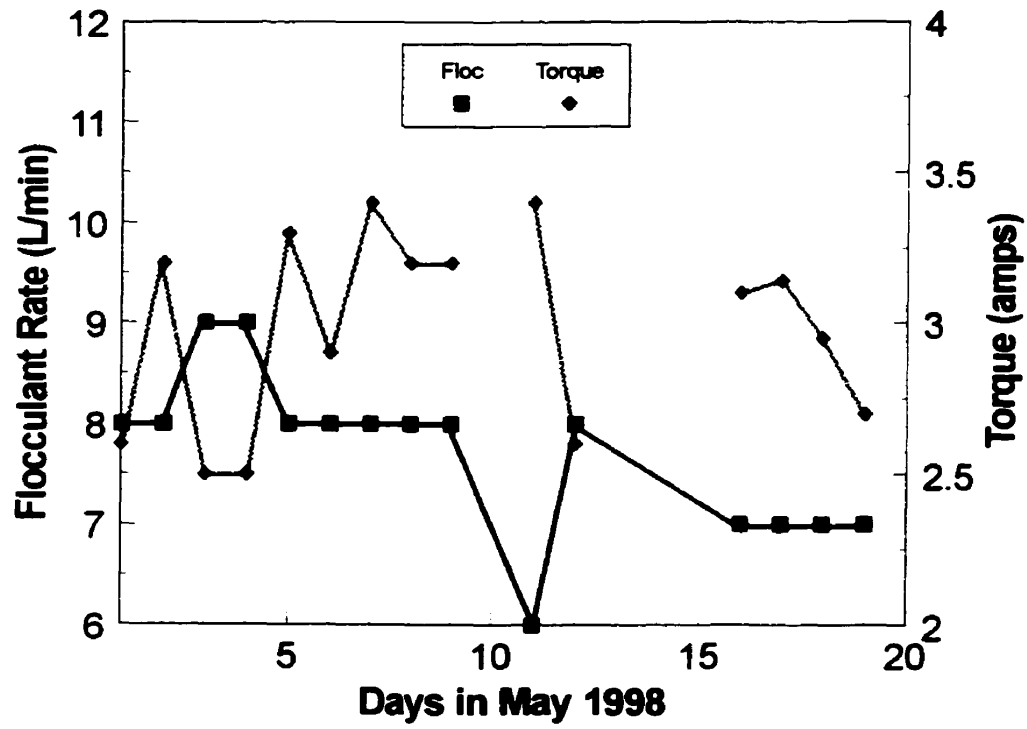


(b)

Figure C.6: Torque and flocculant rate for April 1998 at (a) 12 am and (b) 4 am.



(a)



(b)

Figure C.7: Torque and flocculant rate for May 1998 at (a) 12 am and (b) 4 am.