final report

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Electrocoagulation Process for Wastewater Treatment

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Contents

1 Executive Summary

A pilot scale Electrocoagulation (EC) unit (supplied, commissioned and trialed by EC Pacific Pty Limited, Sydney) capable of treating approximately 10 kilolitres/hour (kL/h) was installed at Burrangong Meat Processors (BMP) in Young in May 2000. Trials were conducted to determine the unit's performance in treating cooled, diluted stickwater from the facility's Low Temperature Rendering Plant. Initial focus during the first year was on establishing the best type of equipment to permit separation of the EC sludge from the treated effluent. Later studies (November 2001 – May 2002) addressed the operating parameters for best performance of the EC unit.

Electrocoagulation operates by passing the effluent across metal electrodes. These are either aluminium or iron plates, or a combination of both. The electrical DC current solubilizes metal ions, which promote coagulation and flocculation of the organic material, which subsequently separates as a floating, frothy sludge in the downstream sludge separation unit. The treated liquid effluent is discharged for further treatment or into the sewer. A pilot scale electrocoagulation (EC) unit (supplied, commissioned and trialed by EC Pacific Pty Limited. The sludge can be recovered and blended with the meat meals. The EC unit at Young has 29 electrodes. It was operated in batch mode, but is readily used as a continuous unit.

Approximate stickwater composition was a COD of 120,000 mg/L; BOD5 of 35,000 mg/L; TN of 3,000 mg/L; TP of 500 mg/L; and TSS of 23,000 mg/L. Substantial variability in composition was normally found.

Initial trials determined that successful treatment of the undiluted stick water stream could not be obtained, as it was too concentrated. Subsequent trials found that good results could be achieved by diluting the stickwater stream 1:1 with recycled treated effluent (final product of the BMP effluent treatment plant). Use of the general abattoir raw wastewater (termed "bloodwater" in this report) was successful only if treated first to remove the free, not emulsified fat. Otherwise, the fat can become deposited on the electrodes, form an insulation layer and prevent the current from passing between electrodes. This did not occur when stickwater was diluted with potable water or recycled final effluent from the BMP treatment plant.

Typical operating conditions giving good results on 1:1 diluted stickwater (at 27 – 30^{o}C) were a flow of 4.5 kL/hr with treatment at 200 Amps, 50 V (DC). A mix of iron and aluminium electrodes gave best results. Under these conditions the EC-treated wastewater exits the unit as a frothy stream, which rapidly separates in the downstream saveall unit to give creamy coloured floating sludge.

Due to the wide variation in operating conditions trialed, it is difficult to determine "average" performance of the EC unit treating diluted (1:1) stickwater. However, a conservative estimate of performance drawn from an analysis of typical trials is given in the Table below. Once near optimal operating conditions are determined, it is expected that the "typical" performance (given in the table as "Under optimal conditions") would be a probable outcome. Such performance was observed in the later trials.

Table 1: Conservative estimate and probable "typical" pollutant removals for the electrocoagulation unit treating 50% diluted stickwater

% Removal	COD	TSS	TKN	TP	O&G
Conservative estimate	85	90	50	70	90
Under optimal conditions	90	95	65	90	95

This performance is similar to that observed for chemically dosed dissolved air flotation units (DAF), but without the operating cost of added chemicals and with superior solids concentration in the float.

The treated effluent had little increase in metal concentration (normally concentrations of either metal were less than 50 - 100 mg/L). The majority of the solubilised aluminium or iron was found in the EC sludge. The sludge properties were typically:

10 – 15% total solids

0.3 – 3% w/w (based on dry sludge weight) of aluminium

0.03 – 0.25 % w/w iron

The approximate capital cost of the EC unit of the size used at BMP, including two savealls for sludge separation amounted to A $150,000. Operating power consumption for the treatment approximates 1.5 kWh/kL. Electrode consumption was not determined within this study, but appeared reasonably slow.

The key outcomes of the project are:

- The EC unit successfully treated cooled, 50% diluted LTR stickwater. At the Young plant, the impact of the unit is **the *MINIMUM* reduction of COD, TN and TP loads on the existing wastewater treatment plant by 50%, 33% and almost 40%**, respectively.

- The EC unit would appear to best suit **high strength** streams.

- The EC unit acts to **precipitate the organic and nutrient material** in the wastewater **as floating sludge**. The volume of final sludge generated is substantial and has properties similar to DAF sludges.

- The sludge tested for **aluminium and iron** during the trials contained relatively high levels of these metals. Although the levels of the metals in the final product – when the sludge is mixed with the bulk of the by-products - **does not appear to be a problem**, the eventual sale or disposal of the sludge in some instances may need consideration.

- In contrast, the **EC treated effluent was relatively free of the metals**. This makes the EC unit an excellent choice for effluent treatment where irrigation is being considered.

The success of the technology is apparent in that the abattoir has confirmed its intention to bring the EC unit on-line as a permanent part of the treatment system.

2 Introduction

2.1 Background

Burrangong Meat Processors (BMP) is a sheep, pig and beef abattoir. Over the past 15 years the abattoir has undergone considerable improvement and expansion. Consequently the production of waste products from the abattoir has also increased.

In response to increasing environmental pressures and regulations the Burrangong Meat Processors took part in a research project conducted by EC Pacific Pty Limited, investigating the application of electrocoagulation in the treatment of wastewater generated by the abattoir, its optimisation and further development.

2.2 Electrocoagulation – overview of the technology

Coagulation is one of the important physio-chemical operations used in water treatment. This is a process used to cause the destabilisation and subsequent aggregation of smaller particles into larger complexes. Water contaminants such as ions (heavy metals) and colloids (organic and inorganic) are primarily held in solution by electrical charges. Colloidal systems could be destabilised by the addition of ions of the charge opposite to that of the colloid. The destabilised colloids can then aggregate and subsequently be separated from the wastewater.

Coagulation can be achieved by both the **chemical** or **electrical means**.

Chemical coagulation has been used for decades to destabilise suspensions and to effect precipitation of soluble species and other pollutants from aqueous streams. Alum, lime and polymers are some of the chemical coagulants used. These processes, however, tend to generate large volumes of sludge with high bound water content which can be difficult to separate and dewater. The processes also tend to increase the total dissolved solids content of the effluent, making it unacceptable for reuse within industrial applications.

Other aspects of chemical coagulation are also becoming increasingly less acceptable. The disposal cost of the large volumes of sludge (generally of fairly high hazardous waste category), the cost of the chemicals required to achieve coagulation and the environmental issues associated with the process are critical problems in many industries.

Electrocoagulation, the passing of the electrical current through water, has proven very effective in the removal of contaminants from water. Electrocoagulation systems have been in existence for many years using a variety of anode and cathode geometries, such as plates, balls, fluidised bed spheres, wire mesh, rods, and tubes.

Although the **electrocoagulation** mechanism resembles the chemical coagulation - the cationic species being responsible for the neutralisation of surface charges – in many ways it is very different.

Electrocoagulation is a process of destabilising suspended, emulsified or dissolved contaminants in an aqueous medium by introducing electrical current into the medium. The electrical current provides the electromotive force causing the chemical reactions.

Several **distinct electrochemical processes** occur during the electrocoagulation process independently.

Processes occurring:

- **Seeding** resulting from the anode reduction of metal ions that become new centres for larger, stable, insoluble complexes
- **Emulsion breaking** resulting from oxygen and hydrogen ions reacting with emulsified substances and forming water insoluble material
- **Halogen completing** - as the metal ions bind themselves to halogens resulting in formation of large insoluble complexes and isolating pesticides, herbicides, chlorinated PCBs, etc.
- **Bleaching** by oxygen species produced in the reaction chamber and providing oxidisation of chemical substances and also reducing bio-hazards through oxidisation of bacteria, viruses, etc.
- **Electron flooding** of the water affects the polarity of water, allowing colloidal materials to precipitate. The electrons create osmotic pressure rupturing cell walls of bacteria, cysts, and viruses
- **Oxidation and reduction reactions** are forced to their natural end point. Electrocoagulation can speed up the natural processes occurring in wet chemistry

Electrocoagulation induced **pH** typically shifts towards neutral.

The principal cathodic reaction is the reduction of hydrogen ions to hydrogen gas ($2H^+ + 2e^- = H_2$). The principal anodic reaction is the release of metal ions into solution (eg. $3Al = Al^{3+} + 3e^-$). The anodes are sacrificed during the process. The wastewater passes through a chamber with the cathodes and anodes. The electrical current is introduced via parallel plates constructed of metals selected to optimise the removal process. The two most common plate materials are iron and aluminium. In accordance with the Faraday's Law, the metal electrodes are sacrificed and slowly dissolve into the liquid medium. The metal ions tend to form metal oxides that electromechanically attract the destabilised contaminants.

The anode materials (iron, aluminium), spacing and lengths, applied amperage, voltage and waste water characteristics (pH, standard redox potential, conductivity) can be varied and optimised for maximum removal efficiencies of specific contaminants. The polarity of the electrodes can be reversed periodically to assist in cleaning of the electrodes.

After the treated wastewater leaves the electrocoagulation chamber, the destabilised colloids are allowed to flocculate and then separated in an integrated system. The sludge can be further de-watered using a filter press, settling pond, or other de-watering techniques.

Comparisons of the general removal rates:

Parameter	**Electrocoagulation**	**Chemical Coagulation**
TSS	95 to 99%	80 to 90%
BOD	50 to 98%	50 to 80%
Bacteria	95 to 99.99%	80 to 90%

System capabilities:

- Removes heavy metals;
- Removes suspended and colloidal solids;
- Destabilises oil and other emulsions;
- Removes fats, oils and grease;
- Removes complex organics; and
- Destroys and removes bacteria, viruses and cysts.

Benefits:

- Treats multiple contaminants;
- Sludge minimisation;
- Capital cost significantly less than conservative technologies;
- Operating cost significantly less than conservative technologies;
- Low power requirements;
- Generally no chemical additions;
- Low maintenance;
- Minimal operator attention; and
- Consistent and reliable results.

3 Project chronology and progress

3.1 Initial tests conducted at BMP

The preliminary tests conducted while using the EC Pacific Pty Limited portable bench top demonstration unit first commenced in **April 1999**.

The results, particularly regarding the levels of phosphorus removal, were extremely encouraging. Further tests were conducted in May and June and proved encouraging.

The bench top preliminary electrocoagulation effluent studies have been completed during 2000. The costs of the trials and the cost analyses of the samples taken during this experimental period of time were covered by the BMP.

The purpose of the project was to investigate this new technology from the point of view of the meat processors and their increasing needs regarding the wastewater treatment.

3.2 Full scale experiments and the history of the progress

The Burrangong Meat Processors purchased the large-scale electrocoagulation unit (EC unit - of the capacity of up to 10 kL/ hour) from EC Pacific Pty Ltd. The unit was installed in **May 2000** and the trial tests commenced soon after.

The sludge separation and dewatering system was ultimately designed in a process of cooperation between BMP and EC Pacific Pty Ltd. after several unsuccessful attempts while using commercially available sludge separation systems.

Initially the company involved in the investigations of the sludge separation was Outokumpu. In **November 2000** Outokumpu designed the first 'EC clarifier' installed in combination with another EC Pacific electrocoagulation pilot plant. The plan was to make the final decision on the design of the clarifier after the pilot study for this particular client was completed and implement the experience gained during the pilot study in the final design.

Unfortunately, this particular design was not delivering optimal performance results for the purpose of our project. The pumping of the processed effluent (including the sludge developed in the electrocoagulator chamber) was too aggressive and some damage to the developed floc was occurring. The clarifier was designed to work with the polymer addition to assist the flocculation. As the aim of this project is using no polymer to assist with the flocculation if possible with the idea of the sludge reuse, it was necessary to look for a system where the physical properties of the sludge produced by the electrocoagulation unit – its initial floating tendency - were fully utilized. A decision was made against installing the clarifier of the same design at the BMP premises.

At that stage a large reactor chamber was designed and manufactured to accommodate the needs related to the high concentration of the effluent treated.

The next attempt to separate the sludge from the processed wastewater involved using an IAF unit (Induced Air Flotation Unit) installed downstream from the electrocoagulation unit and gravity fed, in hope that it would suit our purposes better than a clarifier. The design came from Patrick Charles Pty Ltd. the unit was purchased by BMP and was installed in **October 2001**. The volume of the unit was approximately 30 kL, and it was installed in a bunded area downhill from the electrocoagulation unit, at about 20 m distance from the electrocoagulation unit. Fine air bubbles were supposed to assist with the floating of the sludge and help it to keep at the surface and from where the sludge would get collected.

The commissioning of the system took place on October 30 with the help of Dr Peter Donaldson, Filtration Solutions Pty Ltd.

However, the aerator was causing far too much turbulence and disturbance to the floc developed in the EC reactor. The position of the aerator in the unit disturbed the already floating sludge layer and the separation was not nearly as elegant as was hoped for.

The distance of the IAF unit from the electrocoagulation unit electrocoagulation unit also seemed too great, and the initial quality of the sludge and the tendency of the freshly produced sludge to float at the surface of the processed liquid was highly compromised. The unit was decommissioned in **November 2001**.

After these unsuccessful attempts a decision was made by BMP and EC Pacific Pty Ltd to develop their own sludge separation unit, based on their direct experience with the EC produced sludge behaviour. The new sludge separation unit immediately follows the electrocoagulation reaction chamber. The unit is made by BMP. It is a rectangular tank with a surface scraper following the reactor and bypassing the development tank, which is normally a part of a standard electrocoagulation unit. The unit was designed, built and installed by the end of **November 2001**. Good results were obtained and a decision made to build another similar unit into which the sludge from the first separator would be transferred and within which further dewatering would take place.

The second separator was built and installed in early December 2001. The floating sludge from the first separator is directed into the second separator, the sludge is again scraped from the surface and moved to the end of the separator and collected. Same dewatering process takes place as it does in the first separator resulting in sludge solids levels at times as high as 19 %.

Regular test trials were performed and samples taken between **December 2001 and May 2002** working mostly with different electrode configuration, material and various mixtures of stick water, blood water and fresh water. In **April 2002** a trial test was performed using a **Spinifex oil separator** (Spinifex Australia Pty Limited) for pre-treatment of the effluent from the kill floors (blood water) prior to the electrocoagulation treatment.

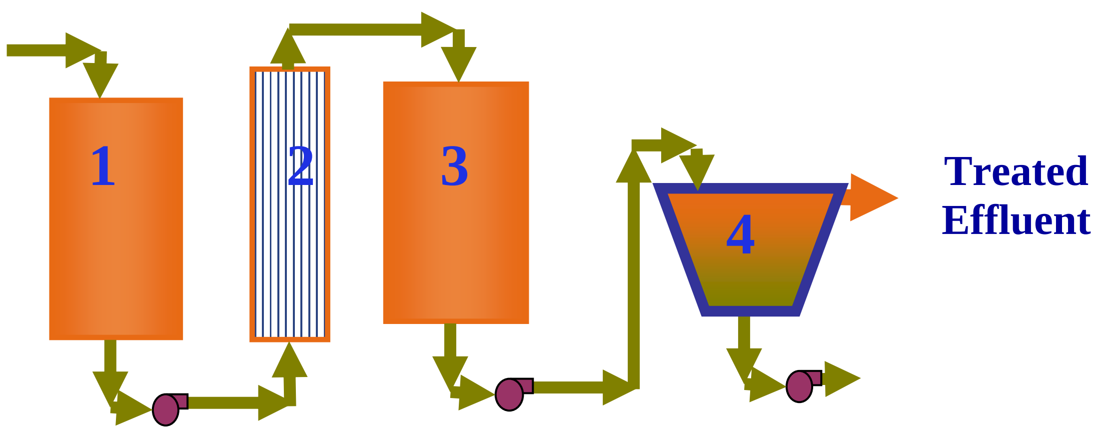
The removal of the free fat eliminated the deposition of the fat on the electrodes, which occurred when strait 'blood water' from the abattoir production lines was processed by the EC unit.

4 Electrocoagulation – performance and operation

4.1 Description of the EC unit

The diagram in as shown in Figjure 1 represents the schematic of the general electrocoagulation process. A typical system includes: a feeding tank **(1)**; the reaction chamber with electrodes **(2)**; a development tank **(3)** where the reactions initialised within the reaction chamber complete; and a sludge separation unit **(4)**, specific to various types of effluent treated. The system installed at the BMP abattoir does not include the development tank **(3)**, as the process takes place fully within the reactor and the sludge is ready for the separation immediately after leaving the reactor. There are two sludge separation tanks (numbered 1 and 2)

Figure 1 EC unit schematic flowsheet



Parts of the unit:

- Power supply
- Surge-feeding tank (1)
- System pumps
- Reaction chamber (2)
- Electronic control system
- Two sludge separation units (4)

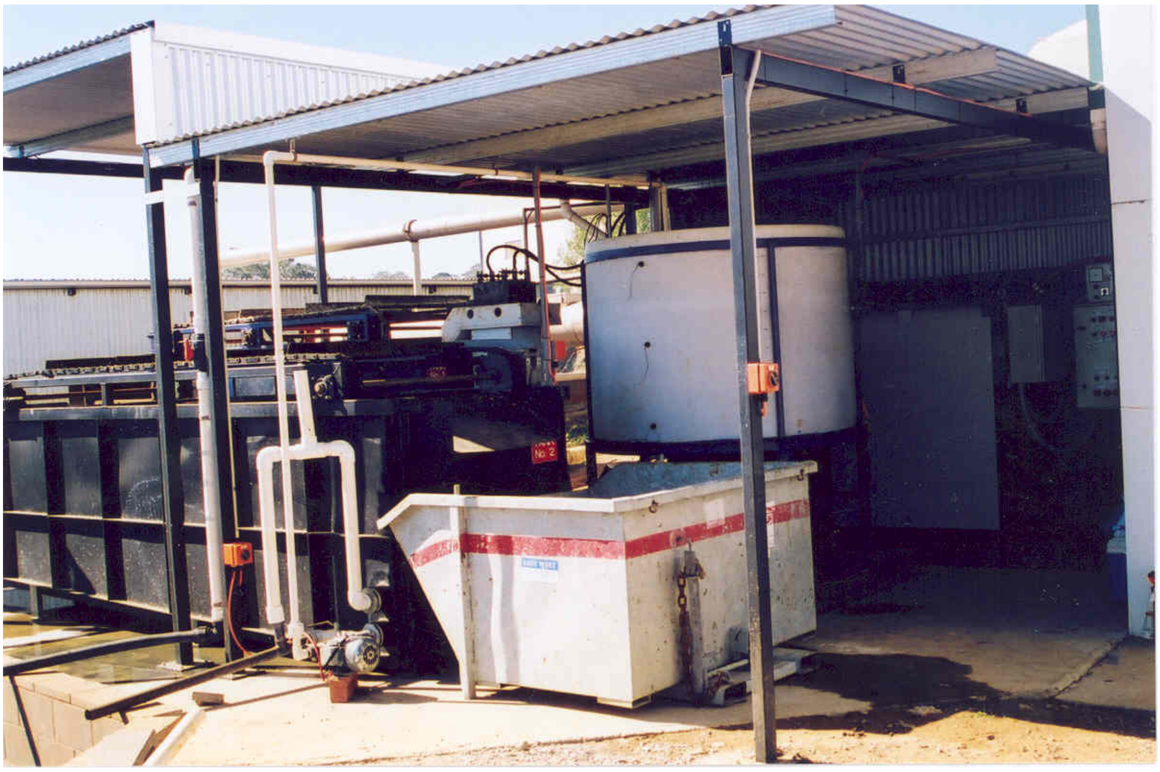


Figure 2: Electrocoagulation system at BMP, Young, NSW

The electrocoagulation unit installed at the BMP premises has a nominal capacity to treat **10 kL/hour**. As the effluent treated at BMP happens to be highly concentrated, the unit has been operated at only about 50-75 % of its nominal flow capacity. The power is supplied to the unit by a primary power source capable of supplying 3 phase 415 V, 100 Amp. The output of the power supply of this unit is 0-750 Amp (DC), and 0-75 V (DC).

The effluent for the treatment is pumped into the surge-feeding tank (2 kL capacity), where the acquired concentration or mixture of different streams for the treatment is achieved.

At the current stage of the operation the desired dilution of stick water is achieved in the surge (feeding) tank and all the experiments were based on batch processing.

From the surge tank the effluent is pumped to the electrocoagulation chamber. The electrodes in the chamber are positioned vertically; the wastewater is fed into the chamber from the bottom of the chamber and discharged from the top. The residence time within the chamber is typically about 20 seconds.

Figure 3: Power supply and operating panel

Figure 4: Processed wastewater leaving the electrocoagulation chamber

From the electrocoagulation chamber the treated wastewater is discharged directly into the sludge separation Tank 1, the sludge is scraped from the surface and transferred to the Tank 2.

The treated wastewater is discharged from the lower level of the separation Tank 1. The sludge in the Tank 2 is processed and handled in the same way, scraped from the surface and transferred to the collection bin from which it is pumped away – either to be utilised and mixed with the meat meal material in the drier or disposed of in some alternative way.

The processed effluent is ultimately gravity fed to the anaerobic pond and processed together with the rest of the abattoir wastewater.

Figure 5: Sludge separator 1

Figure 6: Sludge mass in separator 1

Figure 7: Sludge leaving separator 2

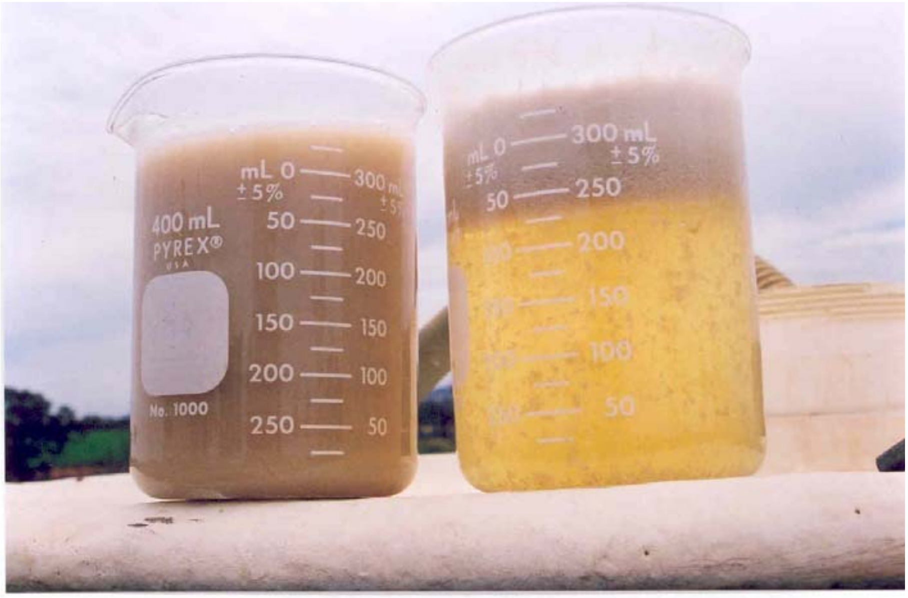


Figure 8: Raw and freshly processed stick water sample

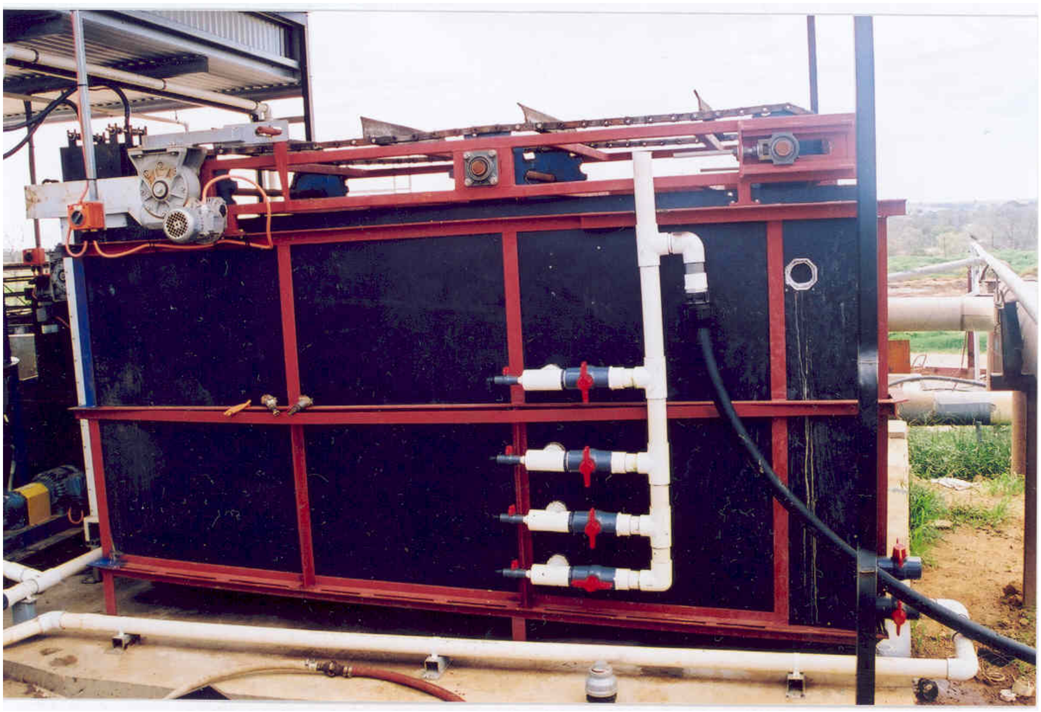


Figure 9: Processed wastewater sampling points – sludge separator 1 (Tank 1)

4.2 Operation of the EC plant

The mode of operating of the unit is very much based on the operators experience with the particular type of wastewater. The operator has to be able to assess the quality of the floc produced and set the variables (amperage, voltage, electrode material, flow) accordingly to produce the best results.

Once working with wastewater of reasonably known and constantly uniform nature, the unit is set in a particular way and would operate automatically, without the need of constant attention. The technology is able to accommodate certain level of wastewater parameter variations and still treat the effluent adequately, but a considerable difference in the incoming flow requires the operator's attention and modifications to the setting of the machine.

Through numerous trials undertaken during the period of time between May 2000 and May 2002 at the BMP plant, conclusions have been made regarding the mode of operation of the unit summarised in chapter 4. Results.

Different mixture ratios of stick water, blood water, fresh water and final effluent from the BMP wastewater treatment plant (irrigation water) were tried and processed using various combinations of aluminium and iron electrodes, applying various combinations of amperage and voltage and manipulating the flow size.

The stick water processed by the system originates in a low temperature rendering plant it is fairly acidic (typically about pH = 4.5), relatively low in free fat content.

4.3 Testing and analysis

The full-scale unit testing involving chemical analysis did not commence until November 2001. Until then the investigations of the practicalities of the process, the constant development of the unit and the fact that the sludge separation facility was not satisfactorily performing would make the chemical testing of the processed effluent meaningless.

Previous to the chemical testing, during the period of the development of the unit, the process results were evaluated mostly visually based on experience and the comparison of the processed wastewater with the results achieved on small scale using the demonstration unit.

The laboratory conducting the chemical analysis was the Australian Laboratory Services Pty Limited (ALS), Smithfield, NSW.

During the initial phases of the project the treated effluent samples were collected after the processing and the sludge removal was achieved though gravity separation. Since the installation of the sludge separation tanks (1+2) the samples of the treated effluent were collected from the lower parts of the Tank 1, the sampling points shown in Figure 8.

The sludge samples were collected directly as the sludge leaves Tank 2.

The water samples were collected in a plastic jug and transferred into the bottles provided by the laboratory, with the appropriate fixatives, when required.

EC Pacific delivered the samples to the laboratory as soon as possible after the sample collection. Chilled containers provided by the laboratory were used.

Tests performed and methods used (ALS method coding):

- pH (measured by EC Pacific);
- COD (as BOD sampling proved difficult considering the nature of the sample and the transport issues) – EP – 026;
- suspended solids – EA – 025;
- total Kjeldahl nitrogen – EK-061A;
- total phosphates – EK- 067A;
- total oil and grease – EP –020;
- occasional total dissolved solids – EA –027;
- aluminium – EG – 005T;
- manganese – EG - 020F;
- iron – EG – 005T; and
- moisture content – EA - 055.

Temperature of the wastewater was measured and the power supply conditions recorded by EC Pacific.

It proved not practical to test the treated effluent samples for ammonia and total dissolved solids (TDS), as the raw samples (before the treatment) were far too concentrated (particularly too high in suspended solids) to be meaningfully tested for these two parameters.

5 Results

5.1 Stick water concentration and wastewater pre-treatment

During the preliminary (bench top) tests the best results seemed to have been achieved when the ratio of **stick water** (rendering plant effluent) and **blood water** (abattoir effluent from the kill floors, free fat screened out) was about 20:80.

As the large size unit installed at the BMP premises shows much higher efficiency compared to the demonstration unit, contrary to the preliminary tests the **optimal stick water concentration** was found to be approximately **50%.**

The trials involving any combination of stick water and blood water – or blood water alone presented difficulties in terms of gradual blinding of the electrodes caused by a thin film of fat deposits. That is caused by the large quantity of free fat in the abattoir effluent.

In such case the fat accumulation the electrodes become insulated and the current cannot freely flow. The performance of the system is compromised and the quality of the sludge is poor.

For that reason a lot of the work undertaken included working with alternative dilution material for the stick water – fresh water and treated effluent was used to dilute the concentrated stick water. When stick water was processed alone or diluted by potable water or treated abattoir effluent the problem did not occur.

The employment of a Spinifex hydrocyclone unit used for the removal of the free fat from the blood water, the fat deposit issue is no longer relevant, and the blood water (when most of the free fat removed) is very efficiently processed in combination with stick water. That is a significant improvement, as diluting the stick water with the other mentioned materials is really of much lower commercial benefit.

5.2 Electrodes

The original – smaller – electrocoagulation chamber, which was used during the first year of the experiments, only had 9 electrodes. The current version of the reactor has 29 electrodes. Not all the electrodes are connected to the power source, the number and the configuration of the connected electrodes varies depending on the conductivity of the material processed. In the gaps between the connected electrodes unconnected electrodes are present, still functional in the flow of current, but not introducing the current into the chamber.

The electrodes connected to the power supply are positioned in a symmetrical way, with the gaps between them as equal as possible and with the number of anodes and cathodes identical if possible.

It is a feature of the EC Pacific Pty Ltd systems that the polarity of the electrodes automatically periodically changes (typically every 10 minutes). That assists with possible cleaning of the electrodes if any accumulation of material on the electrodes should occur.

The electrodes are sacrificial and certain amount of the dissolved metal is used in the sludge formation, some minute amounts remain in the effluent.

The best results were ultimately achieved using a combination of iron and aluminium electrodes. The presence of aluminium in the process is very beneficial for the phosphorus removal and the optimal sludge appearance, but the aluminium electrodes are used for the electrodes that are not connected to the power supply and iron electrodes for the connected blades. The best results are achieved while using a combination of both materials.

That benefit of using both metals is a slower rate at which the aluminium electrodes are being used up, while the aluminium electrodes are still present and functional.

5.3 Flow size

The flow rate of the unit is adjustable. It has a dial calibrated from 0 – 10, controlling the pump flow rate.

The relationship between the setting of the dial and the flow rate is not strictly linear.

The final optimal flow rate used in the experiments was speed setting 6.5 corresponding with the **4.5 kL/hour** flow size.

5.4 Influence of temperature and pH variations on the performance of the system

The temperature of the wastewater to be treated and the stream leaving the electrocoagulation chamber was taken.

The initial temperature of the stick water received for processing is typically about **45 – 47^{o}C.** When diluted (and at this stage all our experiments involved batch processing only) the temperature drops to typically **27 – 29^{o}C**.

Temperature measured at the outlet of the electrocoagulation chamber is typically about **30^{o}C**.

The temperature of the incoming stick water varies during the day and depends on the particular operation currently taking place in the rendering plant. There are also temperature variations experienced through the seasonal temperature fluctuation.

These relatively small temperature variations have been found to have no practical bearing on the performance of the system. The experience from other electrocoagulation applications suggests the same conclusion of the temperature variations being of no particular importance.

5.5 Comments

An interesting observation seems to be that on the days when **only** the mild steel (iron) electrodes were used in the electrocoagulation treatment the ability of the sludge in the aerobic pond (where the EC treated wastewater is gravity fed) to settle and the clarity of the water in the aerobic pond was significantly better that usual. The colour of the processed effluent when iron electrodes used only can be dark, almost black. The processed effluent was tested for manganese in the attempt to identify the black material, but the low manganese levels did not confirm the theory of the manganese causing the colour of the treated effluent.

5.6 Tabulated results

Terms used in following tables:

Raw – untreated wastewater;

Polymer – polymer treated wastewater;

Processed – electrocoagulation treated wastewater;

Stickwater – wastewater generated in the low temperature rendering facility;

Al – aluminium electrodes used;

Fe – iron electrodes used; and

Al, Fe – combination of electrodes used.

Table 2 shows the analytical results of the preliminary tests conducted using the EC Pacific Pty Ltd portable bench top demonstration unit. The testing began in April 1999.

The results achieved using the laboratory scale electrocoagulation unit (in Table 2 under "processed") are on one occasion compared with a set of results achieved through chemical coagulation using polymers ("polymer") only for phosphorus removal (30/4/99).

Table 2. Preliminary results

Date and sample description	Electrode material	pH	Units	BOD	SS	Total N	Total P	TDS
30/04/1999								
Blood water 100%	Al							
Raw		n/a	mg/L	6 800	n/a	n/a	100	n/a
Polymer		n/a	mg/L	n/a	n/a	n/a	100	n/a
Removal % (polymer)							**0%**	
Processed (EC)		7	mg/L	n/a	90	790	0.9	1 200
Removal % (EC)							**99%**	
Stick water 100 %	Al							
Raw		n/a	mg/L	35 000	22 000	3 010	580	n/a
Polymer		3.1	mg/L	n/a	n/a	n/a	360	n/a
Removal % (polymer)							**38%**	
Processed (EC)		4.9	mg/L	n/a	3 700	n/a	70	13 000
Removal % (EC)					**83%**		**88%**	**62%**
3/06/1999								
Stick water 100 %	Al							
Raw		3.5	mg/L	33 000	23 000	2 800	560	44 000
Processed (EC)		4.1	mg/L	15 000	6 200	1 700	140	23 000
Removal %				**55%**	**73%**	**39%**	**75%**	**47%**
Stick water 10 %	Al							
Blood water 90 %								
Raw		4.4	mg/L	6 200	3 300	730	130	4 300
Processed (EC)		5.1	mg/L	2 400	300	300	12	3 800
Removal %				**62%**	**91%**	**59%**	**91%**	**12%**

The table summarises the results of the analysis during the course of sampling, describes the sample dilution and the material used for the stickwater dilution, the power consumption during the test, states the material of the electrodes and shows the removal rates.

The table illustrates the progression of the project, and indicates that the optimisation of the process was increasing towards the end of the project.

Date and sample description	Electrode material, flow rate	Amps	Volts	pH	Units	COD	SS	TKN	Total grease	Total P	TDS	Al	Fe
15/11/2001													
Stick water 50 %	Al	500 Amp	12 V										
Fresh water 50 %	5kL/hour												
Raw				3.42	mg/L	9 560	7 960	1 050	2 600	139			
Processed				3.75	mg/L	4 560	372	790	<5	71			
Removal %						**52%**	**95%**	**25%**	**99.9%**	**49%**			
Stick water 25 %	Al	450 Amp	18 V										
Fresh water 75 %	4.2kL/hour												
Raw				3.87	mg/L	10 200	8 280	969	4 010	150			
Processed				4.18	mg/L	3 440	315	682	44	52.7			
Removal %						**66%**	**96%**	**30%**	**99%**	**65%**			
29/11/2001													
Stick water 50 %	Al, Fe	450 Amp	22 V										
Fresh water 50 %	3.3kL/hour												
Raw				4.02	mg/L	14 800	15 400	1 750	6 890	229	10 520	0.25	3.14
Processed				4.64	mg/L	5 770	540	1 190	46	94	10 400	1.38	249
Removal %						**61%**	**96%**	**32%**	**99%**	**59%**	**2%**		
Stick water 25 %	Al, Fe	450 Amp	27 V										
Fresh water 75 %	3.3kL/hour												
Raw				4.25	mg/L	5 240	3 840	505	2 330	75	4 700	0.11	0.93
Processed				5.94	mg/L	2 260	720	387	72	29	3 690	1.39	208
Removal %						**57%**	**81%**	**23%**	**97%**	**61%**	**21%**		

Table 3A. BMP tests results

Date and sample description	Electrode material, flow rate	Amps	Volts	pH	Units	COD	SS	TKN	Total grease	Total P	TDS	Al	Fe
6/02/2002													
Stick water 50 %	Al	600 Amp	50 V										
Fresh water 50 %	3.8kL/hour												
Raw				4.5	mg/L	4 130	4 490	702	621	94.6			
Processed				4.7	mg/L	2 780	99	301	16	10			
Removal %						**33%**	**98%**	**57%**	**97%**	**89%**			
Stick water 25 %	Al	350 Amp	75 V										
Blood water 75 %	3.1kL/hour												
Raw				4.5	mg/L	5 030	2 750	1 560	454	134			
Processed				4.8	mg/L	2 005	76	660	<5	21.1			
Removal %						**60%**	**97%**	**58%**	**99%**	**84%**			
Stick water 50 %	Fe	200 Amp	42 V										
Blood water 50 %	3.1kL/hour												
Raw				4.2	mg/L	7 470	2 820	792	420	77			
Processed				5	mg/L	5 200	865	649	78	49.5			
Removal %						**30%**	**70%**	**18%**	**81%**	**36%**			
Stick water 50 %	Fe	270 Amp	63 V										
Blood water 50 %	3.1kL/hour												
Raw				4.2	mg/L	7 470	2 820	792	420	77			
Processed				5.7	mg/L	4 840	67	641	51	36.8			
Removal %						**35%**	**98%**	**19%**	**88%**	**52%**			

Table 3B. BMP tests results

Date and sample description	Electrode material, flow rate	Amps	Volts	pH	Units	COD	SS	TKN	Total grease	Total P	TDS	Al	Fe
14/02/2002													
Stick water 50 %	Fe	200 Amp	42 V										
Blood water 50 %	3.1kL/hour												
Raw				5.5	mg/L	7 470	2 820	792	420	77			
Processed				7	mg/L	5 200	865	649	78	49			
Removal %						**30%**	**69%**	**18%**	**82%**	**36%**			
Stick water 50 %	Fe	270 Amp	63 V										
Blood water 50 %	1kL/hour												
Raw				5.5	mg/L	7 470	2 820	792	420	77			
Processed				7	mg/L	3 440	67	641	51	36.8			274
Removal %						**54%**	**98%**	**19%**	**88%**	**52%**			
6/03/2002													
Stick water 50 %	Al, Fe	350 Amp	60										
Blood water 50 %	3.5kL/hour												
Raw				4.5	mg/L	57 000	9500	1 940	928	251		4.6	6.7
Processed				4.7	mg/L	10 200	1 340	762	43	76		53.7	99.9
Removal %						**82%**	**86%**	**61%**	**95%**	**69%**		**- 91 %**	**- 93%**
Stick water 50 %	Al, Fe	400 Amp	23 V										
Fresh water 50 %	3.1kL/hour												
Raw				4.8	mg/L	60 000	4 540	1 540	131	217		0.63	1.95
Processed				5.2	mg/L	10 500	1 110	1 100	16	46		113	46.7
Removal %						**83%**	**76%**	**28%**	**88%**	**79%**		**- 99 %**	**- 96 %**

Table 3C. BMP tests results

Date and sample description	Electrode material, flow rate	Amps	Volts	pH	Units	COD	SS	TKN	Total grease	Total P	TDS	Al	Fe
24/04/2002													
Blood water 100 % (Spinifex)	Al, Fe 5kL/hour	100 Amp	70 V										
Raw				7	mg/L		620		250				
Spinifex processed				7	mg/L	2 490	590	339	188	52.2			
Processed				7	mg/L	1 420	350	324	11	21		38	2.91
Removal %						**42%**	**43%**	**4%**	**96%**	**60%**			
Stick water 50 % Irrigation eff. 50 %	Al, Fe 3.1kL/hour	250 Amp	40 V										
Raw				5	mg/L		15 400		1 240				
Spinifex processed				5	mg/L	18 100	6 150	3 000	41	487			
Processed				7	mg/L	8 140	2 110	2 050	20	124		159	45
Removal %						**56%**	**86%**	**32%**	**98%**	**74%**			
9/05/2002													
Stick water 50 % Spinifexed blood water 50 %	Al, Fe 4.5kL/hour	200 Amp	50 V										
Raw				4.5	mg/L	160 000	13 500	1 670	241	212		1.62	3
Processed				5.5	mg/L	3 990	238	525	87	12.7		4.82	29.8
Removal %						**98%**	**98%**	**69%**	**64%**	**94%**		**- 66%**	**- 90 %**
Stick water 50 % Spinifexed blood water 50 %	Al, Fe 4.5kL/hour	300 Amp	47 V										
Raw				4.8	mg/L	69 800	16 300	2 120	366	231		1.05	2.72
Processed				5.2	mg/L	4 590	211	548	22	46		5.82	27.9
Removal %						**93%**	**99%**	**74%**	**94%**	**92%**		**- 82 %**	**- 90 %**

Table 3D. BMP tests results

6 Discussion

6.1 Removal rates achieved

The removal rates achieved in the course of this project are extremely encouraging.

Table 4 represents tabulated removal percentages as they were achieved chronologically, disregarding the particular way in which the wastewater was processed and the actual make up of the wastewater. Tabulating the results chronologically in this way is only meaningful when seen as the illustration of the optimisation progress that has been achieved. The average removal percentage shown in Table 4 is of no particular meaning. The individual percentage removal rate results were achieved while the conditions of the individual test runs varied throughout the project, and the objective of the experiment was gradually being achieved towards the end of the project.

Table 4. Removal Percentages

Date	Total P	COD	SS	Total grease	TDS	TKN
15/11/2001	49%	52%	95%	99.9%		25%
	65%	66%	96%	99%		30%
29/11/2001	59%	61%	97%	99%	2%	32%
	61%	57%	81%	97%	22%	23%
6/02/2002	89%	33%	98%	97%		57%
	84%	60%	97%	99%		58%
	36%	30%	69%	81%		18%
	52%	35%	98%	88%		19%
14/02/2002	36%	30%	69%	82%		18%
	52%	54%	98%	88%		19%
6/03/2002	69%	82%	86%	95%		61%
	79%	83%	76%	88%		28%
24/04/2002	60%	42%	43%	96%		4%
	74%	56%	86%	98%		32%
9/05/2002	94%	98%	98%	64%		69%
	92%	93%	99%	94%		74%

The average level **phosphorus removal** for the entire project is **67.67 %**. However, this figure is of limited meaning, as this "average" represents the average value of all the removal rates achieved during the entire project grouped together. It is apparent that towards the conclusion of the project, with the results nearing the optimised performance of the system, removal rates superior to the "average" have been routinely achieved (up to **94%**).

This applies to all the parameters tested.

The **suspended solids and total grease removal** when using the electrocoagulation in the treatment is quite effortless, with the removal rates typically in **90+%.**

The **TKN removal** is on average **35.5 %** but up to **74.1%** has been achieved.

Total dissolved solids (TDS) have not been investigated intensively; the average removal rate is **11.75%**, based on two tested samples only.

The level of **COD** has been on average reduced by **53.1%**, with the best result being **93.4%.**

6.2 Power consumption

As the project progressed the power consumption level had been optimised.

At the conclusion of the project while achieving **the best removal rates** and using combination of iron and aluminium electrodes the power consumption related to the electrocoagulation process taking place in the chamber (excluding the pumping, scrapers, lights etc.) typically was:

200 Amp @ 50 V

while processing **6.5 kL/hour**.

That level of power consumption represents **10 kWh** used to process 6.5 kL of wastewater, **1.54 kWh/kL**.

6.3 Sludge reuse

The sludge produced by the electrocoagulation – unlike the sludges produced in DAFs - is free of large quantities of added chemicals used in a DAF for coagulation.

As the sludge is basically coagulated protein and fat, one of the objectives of this study was to establish how the sludge can be reused and the high quantities of this valuable material can be removed from the wastewater and reused. The conclusion of the experiment is that the sludge can be collected, returned to the drier and processed together with the meat meal material produced during the rendering process.

The levels of iron and aluminium in the sludge produced by electrocoagulation vary, depending on the level of power used and probably the pH.

The background levels of iron and aluminium in dry meat meal (unaffected by the electrocoagulation processing) were analysed and the results were **0.04 g/100g (0.4g/kg)** of **iron** and **0.01 g/100g (0.1 g/kg)** of **aluminium.**

When a batch of meat meal of the weight of approximately 1.2 tonne receives an addition of approximately 200 L of the EC sludge with the solid level of 10 % and the **maximum aluminium level detected** in the EC sludge **(30 g/kg),** the aluminium level in the final product is likely to rise from **0.1 g/kg** to **0.6 g/kg**.

The same calculation for the highest level of iron measured **(2.4 g/kg)** indicates the increased level from **400 mg/kg to 440 mg/kg** in the meat meal.

The levels used in these calculations represent the maximum levels of metals found in the EC sludges. This very high concentration does not even seem very probable to occur frequently. It is quite possible that the sample analysed contained an unusually high levels of metals for reasons impossible to stipulate or there may have been a problem with the laboratory results. The visible rate at which the electrodes wore off during the project suggests much slower transfer of the metals from the electrodes to the sludge. Ten times - and more - lower levels of metals were common throughout the experiment in the EC produced sludge.

Even the increased levels of these two metals in the final meal product do not represent an issue regarding the EC produced sludge reuse – unlike the sludges generated with other technologies.

The following Tables 5A and 5B show the test results of the sludge investigations. Only the sludge results from the final test runs have been tabulated.

Date and sample description	Electrode material, flow rate	Amps	Volts	Units	pH	Al	Fe	Oil & grease	Solids %
15/11/2001									
Sludge - jar separated Stick water 50 % Fresh water 50 %	Al 5kL/hour	500 Amp	12 V	mg/kg	3.75	6 240			
6/02/2002									
Sludge - separator 1 Stick water 50 % Fresh water 50 %	Al 3.7kL/hour	600 Amp	50 V	mg/kg	5.7	16.9		69.9	18%
14/02/2002									
Sludge - separator 1& 2 Stick water 50 % Blood water 50 %	Fe 1kL/hour	270 Amp	18 V	mg/kg	7		27.1	307	10%
6/03/2002									
Sludge - separator 1& 2 Stick water 50 % Blood water 50 %	Al, Fe 3.5kL/hour	350 Amp	60	mg/kg	4.7	8 580	1 670	315	18%
Stick water 50 % Fresh water 50 %	Al, Fe 3.1kL/hour	400 Amp	23 V	mg/kg	5.2	35	1 880	332	7%

Table 5A. BMP sludge results

Date and sample description	Electrode material, flow rate	Amps	Volts	pH	Units	Al	Fe	Oil & grease	Solids %
24/04/2002									
Sludge - separator 1& 2 Blood water 100 %	Al, Fe 5kL/hour	100 Amp	70 V	7	g/kg	3	0.3		
Stick water 50 % Irrigation effluent 50 %	Al, Fe 3.1kL/hour	250 Amp	40 V	7	g/kg	4	0.3		
9/05/2002									
Sludge - separator 1& 2 Stick water 50 % Spinifexed blood water 50 %	Al, Fe 4.5kL/hour	200 Amp	50 V	5.5	g/kg	32	2		12%
Stick water 50 % Spinifexed blood water 50 %	Al, Fe 6.5 4.5kL/hour	300 Amp	47 V	5.2	g/kg	29	1		14%

Table 5B. BMP sludge results

6.4 Electrode consumption and capital cost of the equipment

The electrode consumption rate has not been properly evaluated, as the electrodes used in the final set of trials have not been used up sufficiently to make an accurate estimate of the consumption rate.

Two sets of aluminium electrodes were employed throughout the Project. The original set was abandoned when a new larger reactor was built and a complete new set of electrodes installed. The original electrodes were still capable of being used.

The information acquired from the patent holder of this technology is that the cost of the electrodes consumed is approximately **$ 0.03 – 0.05/kL** of treated wastewater.

An approximate capital cost figure - for general information – a fully automated unit of the capacity used at the BMP (including the power supply, reactor chamber, two sludge separation units, the feeding tank) is in the vicinity of **A$ 150,000,** but individual needs of each project have to be considered, and it would be very difficult to estimate the cost of the infrastructure works involved, which varies a lot from one project to another.

A system capable of treating large quantities of wastewater would be modular, designed for the individual needs of the particular application.

6.5 Full automation

The next step in the development of the system installed at the BMP is full automation of the feeding process and abandoning of the batch processing.

7 Conclusions

The technology has been applied at BMP over a period of 2 years.

A range of different processing options and variables were thoroughly investigated and ultimately excellent results achieved.

The undertaken research and experiments proved that electrocoagulation is a revolutionary technology, significantly underused in wastewater treatment.

The removal rates, particularly for difficult to treat contamination such as soluble phosphorus are much superior to the results achieved using the traditional wastewater treatment methods.

The following conclusions were reached:

- Electrocoagulation can be successfully used for the treatment of wastewater generated in the low temperature rendering facility (stick water).
- The most suitable and economically practical for the EC treatment is a combination of stick water and the kill floor effluent (blood water), in the 50:50 ratio.
- Free fat must be removed from the sheep processing kill floor wastewater before mixed with stick water.
- Typical removal rates are as follows:
    - Phosphorus 70 – 90 %
    - Oil & Grease 90 – 95 %
    - TKN 50 – 65 %
    - TSS 90 – 95 %
    - COD 80 – 90 %
- The sludge produced during the process can be returned to the by products plant and utilised while mixed with the rest of the product.