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Evaluation of stick water evaporation process M.734A

1996

Prepared by:
CMPS&F Pty. Ltd.

ISBN: 1 74036 093 1
Published: July 1996

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MEAT & LIVESTOCK
AUSTRALIA

EXECUTIVE SUMMARY

Introduction

This document details the results of an evaluation of the use of a Double Effect Evaporator (DEE) to reduce the nutrient load and oxygen demand of stickwater effluent from a rendering plant while producing a high protein saleable by-product. The study evaluated the system with respect to:

- energy and water consumption,
- technical operation,
- economic feasibility, and
- ability to produce a high quality effluent.

The DEE was purchased second-hand by QMeat from a milk processing operation and placed into operation upstream of an existing dryer system; the capacity of the DEE exceeds that of the dryer and hence it is not usually run at full capacity. Evaporation is achieved through the application of steam heating under a partial vacuum created by condensing the vapour with circulating cooling water.

Surveys

Sampling surveys were undertaken to ascertain the quantity and quality of the feed and product streams, the energy usage and water consumption. Initial surveys were undertaken with the DEE run at reduced capacity; the three final surveys were undertaken at full DEE capacity, with product directed to the existing treatment system. In this manner the performance of the DEE could be evaluated under both design loading and QMeat operating conditions.

Nutrient Removal

The study concluded that the DEE is extremely effective in concentrating both nutrients and organic pollutants in the final product. On average, more than 99.5% of the initial stickwater nutrient load and oxygen demand was concentrated in the final product producing a condensate effluent of a high quality. However, due to the high influent COD concentrations (154 000 mg/L), this effluent has an oxygen demand (349 mg COD/L) which will necessitate further treatment prior to river discharge; nutrient levels are sufficiently low for direct discharge (8 mg TKN/L and 0.03 mg P/L).

Energy Efficiency

The system was shown to be capable of achieving the above mentioned level of treatment with an energy efficiency of over 70%, however this was highly erratic and unpredictable. The main cause of this variability in efficiency was attributed to reduced heat exchange due to fouling of the calandrias. It was concluded that if fouling could be prevented by adopting a regime of regular cleaning as standard practice and/or by addition of "seed" nuclei[1] to the raw feed, consistently high energy efficiencies could be achieved.

Water Consumption

Water is required during system start-up (0.3 m^3) and shut-down (3.4 m^3) and continuously by the vacuum pump for cooling purposes during operation (0.4 L/s). The latter is separate from the process flows and could be recycled rather than discharged on a once-through basis.

Economic Considerations

The economics of the DEE system were compared to those of conventional activated-sludge technology incorporating biological nutrient removal (BNR). The evaluation highlighted the fact that the economic feasibility of the DEE system relies heavily on the capital cost of the dryer which represents over 90% of the system capital cost. If a dedicated dryer is required, then the 10 and 20 year Net Present Value analysis (NPV) of the DEE system are marginally greater than those for the BNR system. However, on the basis of experience at QMeat, it may be possible to utilise existing dryers used in the rendering process; in this case, the DEE system is considerably less expensive than BNR.

Conclusions

Based on the nutrient removal ability, energy efficiency and possible economic viability, the study concludes that evaporation of rendering plant stickwater appears to be a promising alternative to conventional methods of treatment. It should be noted that a number of problems were experienced during the sampling surveys (incorrect prior calibration of instrumentation, lack of instrumentation and erroneous/ missing data logged to computer) and hence the study has several limitations which may affect the degree of certainty associated with these conclusions.

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[1] Seed nuclei, such as suspended solids or calcium phosphate, circulate within the evaporator and aid the deposition of precipitating solids.

Recommendations

Recommendations include:

- further study of the evaporation of stickwater under controlled conditions to confirm results;
- investigation of plate evaporation as an alternative to rising film evaporation as a means of increasing energy efficiency;
- research into methods of reducing entrainment of contaminants in the cooling water;
- investigation of 24 hour operation of the system at dryer capacity as a means of overcoming the limitations of the dryer capacity and minimising start up and shut down periods;
- installation of a steam trap on the steam condensate lines to stop steam being wasted;
- implementation of a cooling water recycle loop around the vacuum pump to stop wastage of clean water;
- review of the calibration and installation of all instrumentation to ensure reliable operation and results; and
- investigation of the feasibility of using existing dryer facilities at abattoirs to enable a more conclusive economic evaluation to be made.

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1. INTRODUCTION

1.1 HISTORY

The recent review of Australian Environmental Legislation and the introduction of comprehensive environmental regulations in several States has imposed tighter wastewater discharge requirements on industry with increased penalties for non-compliance.

The review addressed the discharge of nutrients to receiving waters and proposed strict limits for discharge as a result. These limits pose a major threat to the abattoir industry as abattoir wastewaters typically contain high levels of nutrient.

Existing treatment systems employed by abattoirs have not been designed for nutrient removal. Traditional systems for nutrient removal, such as those commonly used to treat sewage, will be comparatively expensive in terms of both capital and operating costs and are not usually designed to produce a saleable end-product.

However, as wastewaters from abattoirs contain usable proteins which can be sold if extracted and concentrated, an alternative wastewater treatment system which allows for nutrient separation in conjunction with reclamation of protein, may have economic advantage over traditional methods. To this end, the Meat Research Council (MRC) initiated an investigation into the treatment of stickwater by evaporation.

A full-scale double effect evaporator (DEE) was installed at the QMeat abattoir, Cannon Hill Qld to:

- concentrate stickwater from the rendering process into to a product suitable for drying and hence conversion to a saleable product, and
- produce a wastewater (condensate) of such a quality to allow river discharge to the requirements of the Queensland Department of Environment.

The evaporator operates under vacuum, to lower the boiling point temperature and steam is used to facilitate evaporation.

1.2 CMPS&F BRIEF

On the 10th of August 1995, CMPS&F were commissioned to undertake an environmental, technical and economic evaluation of the stickwater evaporation process. Under this contract, it was agreed that CMPS&F would :

- undertake monitoring and analysis of the DEE,
- undertake a global literature review of wastewater treatment in the meat industry,
- prepare monthly progress reports, and

- prepare a report detailing the results of monitoring and evaluating the environmental, technical and economic viability of the process.

The literature review (Doc No: NE0547-TR-W003) was submitted to the MRC on 19th of January 1996 and is included as Appendix C.

1.3 THIS REPORT

This report is the final report as detailed in the CMPS&F brief, as such it includes:

- DEE survey results (operational and analytical),
- an analysis of these results in terms of nutrient removal efficiency, energy usage and water usage,
- a comparison of DEE with traditional nutrient removal methods in terms of economics and practicalities,
- recommendations for the design of a permanent facility and improvements to the existing operation, and
- recommendations for further research and development.

2. THE RENDERING UNIT

The QMeat abattoir uses a Pfaulder low temperature rendering unit which was commissioned in 1976. This unit has a significant difference in comparison to high temperature units in that water is not boiled off and therefore a higher volume of stickwater is produced.

The rendering process is as summarised below:

1. The abattoir waste is finely ground and heated to rupture cells and cause tallow release. Heating is not sufficient to cause any significant evaporation.

2. The mixture is fed into a decanter whereby solids are separated from the liquid stream and fed to the dryer.

3. The liquid stream, consisting of oil and water, is reheated and fed to the Westfalia separator. This separator uses centrifugal force to produce three streams: oil, stickwater and sludge. Sludge is returned to the decanter.

Discussions with QMeat indicate that regular weekly maintenance of the unit has ensured that performance and efficiency have been kept at a constant level. The amount of oil in the stickwater is maintained at an acceptable level of 1.5%.

3. THE DOUBLE EFFECT EVAPORATOR

3.1 UNIT SIZES

The DEE system is as illustrated by Figure 2.1. Unit volumes have been calculated using on-site measurements and system details provided by Ron Mashford of Q Meat. Unfortunately, pump sizings/capacities could not be determined as no record of this data was available through either Universal Technologies or QMeat.

Unit volumes are:

- Feed tank (T1) 9.0 m^3
- Calandria 1 (C1) 0.7 m^3
- Vapour Head 1 (VH1) 0.8 m^3
- Total First Effect (C1 + VH1) 1.5 m^3
- Calandria 2 (C2) 0.4 m^3
- Vapour Head 2 (VH2) 0.7 m^3
- Total Second Effect (C2 + VH2) 1.1 m^3

3.2 DEE CONTROL

Figure 2.2 shows the instrumentation and control of the DEE. Control loops include those detailed in Table 2.1; instrumentation and device nomenclature refers to that used in the piping and instrumentation diagram (P&ID, Figure 2.2).

Table 3-1
DEE Control Loops

USER INPUT	CONTROLLED VARIABLE	DEVICE	COMMENTS
Calandria 1 Pressure (P 1-1)	Steam Flow (Q 2-9)	Valve (V1)	Maximum nozzle pressure override. Maximum valve opening override.
Vapour Head 1 Level (L 1-8)	Feed Flow (Q 1-4)	Valve (V2)	-
Vapour Head 2 Level (L 1-13)	Transfer Flow (Q 1-10)	Valve (V3)	Also controlled by product density (see below).
Product Density (ρ 2-0)	Product/ Recirc. (F 1-15)	Valve (V4)	Also controlled by Grinder Amps.
Vapour Head 2 Pressure (P 1-12)	Vacuum Pump operation	Pump (P7)	-
Condenser Tube Level (L 2-8)	Cooling Water Flow	Valve (V5)	-

3.3 DEE OPERATION

3.3.1 Start-up

The following sequence is followed to start-up the DEE.

1. Start feed pumps and charge No. 1 Effect.

2. Start transfer pump and charge No. 2 Effect.

3. Start final product/ recirculation pump.

4. Purge system of any water remaining from shut-down procedure by use of three way valve.

5. Start condensate pumps.

6. Start cooling water return and supply pumps.

7. Enter computer set points (Product density = 1.028, No. 1 Effect level = 1500 mm, No. 2 Effect level = 1700 mm).

8. Start vacuum pump (No. 2 Effect pressure = 2 kPa) and run until No. 2 Effect pressure is less than 10 kPa.

9. Start steam input by gradually increasing the pressure in No. 1 Effect (No. 1 Effect pressure = 40 kPa to 65 kPa).

This operation takes approximately 60 minutes.

3.3.2 Production

Product is directed to the dryer when the set point density is reached; lower density products are recycled back to the No. 1 Effect. This set point is usually 1.028.

Due to safety and physical constraints the dryer can only accept a product density of between 1.028 and 1.050 kg/L. The capacity of the dryer is limited and varies according to product density. At densities of 1.028 and 1.05 kg/L, the dryer can accept maximum product flows of 5.4 and 6.2 L/min respectively.

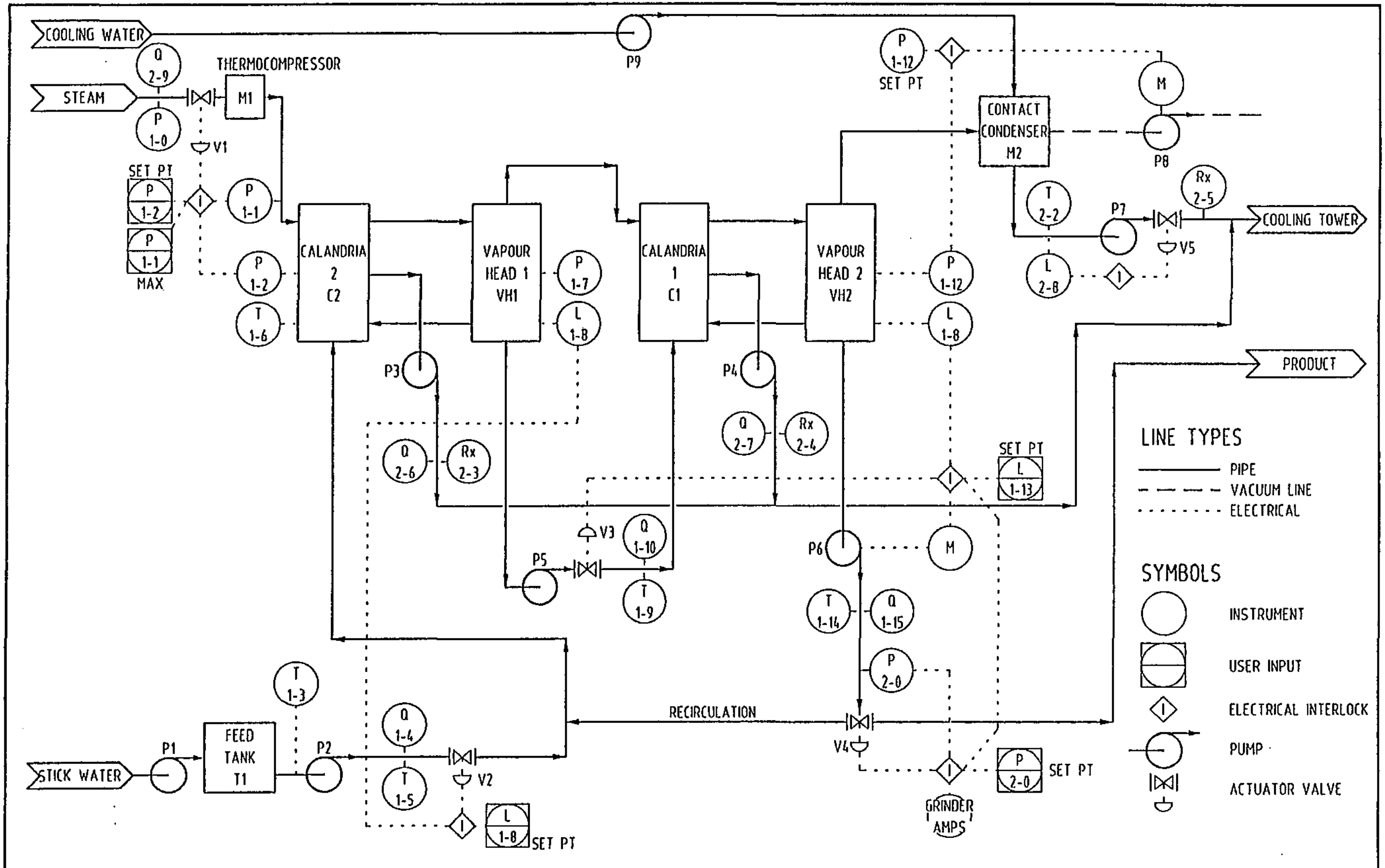
During production, steam input is trimmed to ensure the product density and flow meet the constraints of the dryer.

3.3.3 Shut-down

The following sequence is followed to shut-down the DEE.

1. Close steam valve.

2. Stop vacuum pump.



				CMPS&F ENGINEERS MANAGERS	DRAWN D. REA 9.8.96	QMEAT
				CMPS&F Pty Limited	CHECKED	EVAPORATOR SYSTEM
				66 Eagle St BRISBANE QLD 4000	APPROVED	PIPING & INSTRUMENTATION DIAGRAM
A	ORIGINAL ISSUE			A.C.N. 000 912 630 Tele : (07) 32331811 Fax : (07) 32331849	SCALE N.T.S.	DRAWING No. FIGURE - 2.2 REV A
REV	DESCRIPTION	DATE	APPD		JOB No. NE0547.000	CAD FILE No. NJ00623-

DATE PLOTTED: 19.08.96 TIME PLOTTED 15:24 A3

3. Stop feed pump.

4. Stop cooling water supply and return pumps.

5. Empty system by draining No. 2 Effect and allowing the transfer pump to discharge the contents of No. 1 Effect to No. 2 Effect.

6. Fill No. 1 Effect with clean water (Level No. 1 = 1750 mm, Level No. 2 = 0 mm).

7. Transfer contents of No. 1 Effect to No. 2 Effect (Level No. 1 = 0 mm, Level No. 2 = 1750 mm).

8. Drain No. 2 Effect.

9. Repeat Steps 5., 6. and 7. with Level = 1500 mm.

10. Flush the top of each system by spraying with clean water.

This operation takes between 60 and 90 minutes.

4. METHODOLOGY

4.1 SAMPLING METHODOLOGY

Initial trials were conducted and sampling methodology was reviewed twice. The final sampling methodology is outlined below. It should be noted that instrument failure and industrial action interrupted the program and affected results.

4.1.1 Analytical data

The DEE operation was monitored on eight separate days. During these surveys, samples were taken of the following streams:

- make-up water,
- steam condensate,
- cooling water,
- raw-feed, and
- product.

The samples were taken at fifteen minute intervals and combined to form a composite hourly sample. Due to considerable variation in hourly data obtained from initial sampling, it was decided to analyse half hourly samples rather than composite hourly samples. To effect this, raw-feed samples were taken at fifteen minute intervals and combined to form composite half hourly samples; all other samples were taken at thirty minute intervals. Table 3.1 summarises the information gathered during the surveys.

4.1.2 Operational data

DEE operational data was recorded throughout the day both manually and automatically via the computer. On some days, operational data was printed out at regular intervals throughout the sampling day and where possible, a complete record of this information was obtained on disk. However, problems encountered with the computer have meant that a full set of data does not exist for the eight days spent monitoring the DEE. The operational data obtained on each sampling day are summarised in Table 3.1.

The power consumption of the pumps was obtained from the dedicated electricity meter in the switchroom.

Kill number data for the sampling periods were obtained from QMeat.

4.1.3 Flows

Most flowrates are monitored by the DEE control system. However, cooling tower overflow and cooling water supply to the vacuum pump are not monitored. The flow of these streams was calculated by observing the time taken to fill a vessel of known volume.

Analysis of the flow data has identified that instrument error exists. In particular, the No 1 and No. 2 condensate flow measurements are unreliable due to the fact that much of the flow through this line is in the form of a vapour and consequently is undetected by the liquid flow meter currently installed.

4.2 CALCULATIONS

4.2.1 Nutrient and COD removal ability

The ability of the system to remove nutrient and COD loads from the stickwater stream and produce a "clean" effluent stream suitable for river discharge was primarily assessed by studying the pollutant concentration and total loadings in the cooling water stream. This was achieved using two methods :

- calculating the percentage of the nutrient and COD load entering the system that is removed in the cooling water stream, and

Table 3.1. Summary of Collected Data

DATE	Hours of Data	Kill Data	OPERATIONAL DATA								SAMPLE ANALYSIS: PRODUCT						SAMPLE ANALYSIS: COOLING WATER								SAMPLE ANALYSIS: MAKE-UP WATER (POTABLE WATER)							SAMPLE ANALYSIS: HEATING STEAM CONDENSATE						SAMPLE ANALYSIS: RAW FEED									CALCULATIONS		
			Steam Pressure (kPa g)	Steam Flow (kg/hr)	Raw Feed Flow (l/min)	#1 Condensate Flow (l/min)	#2 Condensate Flow (l/min)	Product Flow (l/min)	Product Density (kg/l)	Transfer Flow (l/min)	Total Solids	TKN	COD	BOD	Total P	Temperature	TKN	NH_3	Total P	COD	BOD	TOC	Temperature	pH	TKN	NH_3	Total P	COD	TOC	Temperature	pH	TKN	NH_3	Total P	COD	Temperature	pH	Total Solids	TKN	NH_3	Total P	COD	BOD	TOC	Temperature	pH	WATER CONSUMPTION	POWER CONSUMPTION	REMOVAL EFFICIENCY
5/12/95	6	Y	Y	Y	Y	Y	Y	Y	[illegible]	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y	-	-	-	Y	Y	-	-	-	Y			Y
7/12/95	6	Y	Y	Y	Y	Y	Y	Y	[illegible]	-	-	-	-	-	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y	-	-	-	Y	Y	-	-	-	Y			Y
16/01/96	6	Y	Y	Y	Y	-	-	Y	Y	-	Y	Y	-	-	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	-	Y			Y
29/04/96	4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-	-	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y			Y
30/04/96	6	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	Y	-	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-	Y	Y	Y	Y	Y	-	Y	Y	Y			Y
1/05/96	4	Y	Y	Y	Y	-	-	Y	Y	Y	Y	Y	-	-	Y	-	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-	Y	Y	Y	Y	Y	-	Y	Y	Y			Y
25/07/96	3.5*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	-	-	-	Y	Y	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
26/07/96	3.5*	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	-	-	-	-	Y	Y	-	-	-	-	-	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

KEY	
Y	Data available
-	Data unavailable / Samples not taken
(black shading)	Calculated using correlation/assumptions from other surveys
(grey shading)	Estimated from other surveys
(grey shading, E)	Erroneous data recorded by QMeat Computer
*	Indicates half hourly data available

- comparison of the cooling water nutrient and COD concentrations with those of the effluent leaving the existing activated sludge treatment plant and the current licence conditions governing discharge of effluent to rivers.

The nutrient removal via the product stream as a percentage of the initial pollutant input was also calculated. However, due to residence time in the DEE vessels and product recycle, evaluation of the removal efficiency on an hourly basis was found to be of little use. Removal efficiency was therefore evaluated on the basis of the total pollutant loads experienced during each survey with an allowance for initial and final reactor contents.

This method of calculation required a number of assumptions to be made regarding the quality of the No. 1 and No. 2 Effect contents prior to and on completion of sampling. These unavoidable assumptions, the variability of the raw-feed and product quality and the standard errors associated with the methods used for sample analysis have made this calculation significantly less accurate than desirable.

4.2.2 Energy consumption

Energy usage was estimated by:

- using steam tables in conjunction with the steam flow and pressure as measured by the DEE control system to obtain enthalpies of steam, condensate, feed and product streams, and

- monitoring the power meter which measures power supplied to the DEE pumps.

Energy usage was calculated using the total flows measured during each survey period.

4.2.3 Water consumption

Water consumption was calculated on the basis of:

- the level drop in the cooling tower reservoir at the beginning of each days' operation,

- the vacuum pump cooling water flow, and

- an estimation of the amount of water used to flush the system at the end of each day.

Water consumption was calculated using total flows measured during each survey period.

4.2.4 Economics

Capital and operational costs for the evaporation process including possible revenue for the protein-rich product were obtained from Bob de Lange at QMeat (Appendix B). Estimates, based on the experience of CMPS&F, were used if data was not readily available.

A Nett Present Value (NPV) analysis was undertaken comparing three different sized evaporative systems with three similarly sized Biological Nutrient Removal (BNR) activated-sludge systems. Capital and operating costs were obtained as follows:

- capital costs for the evaporator systems were obtained from an Australian supplier (APV Australia) (The capital cost of the current evaporator system at QMeat was not used in the NPV analysis as the system was purchased second-hand from a milk processing operation.),
- operational costs for the evaporator were calculated through comparison of the QMeat operational and maintenance costs with manufacturer's estimates,
- capital and operating costs for the dryer were taken from Sydney Water's Cost Estimating Manual which was prepared by CMPS&F, and
- capital and operating costs for the activated-sludge system were taken from Sydney Water's Cost Estimating Manual which was prepared by CMPS&F.

BNR was chosen for comparison with the evaporation system as it was identified by the literature search as one of the more economically feasible options with proven ability to adequately treat rendering plant wastewater. The option is feasible at QMeat as BNR could be retrofitted to the existing activated-sludge treatment plant.

The NPV analysis was undertaken with and without the dryer capital cost. This cost represented over 90% of the DEE option capital cost, significantly affecting the analysis. It may be practical, as is the case at QMeat, to utilise existing rendering plant facilities in which case an additional dryer might not be required.

The NPV analysis was undertaken over a twenty year period and at three different discount rates: 5, 7.5 and 10%. It was assumed that the components of both systems would have a negligible residual value at the end of the 20 year period.

5. RESULTS

5.1 ANALYTICAL DATA

All analytical data is contained in Appendix C. Tables 4.1 to 4.5 summarise the average pollutant concentrations and the total masses experienced during the surveys.

Table 5-1
Average Raw Feed Concentrations

DATE	Total Solids (%)	TKN (mg/L)	NH3-N (mg/L)	Total P (mg/L)	COD ('000 mg/L)	BOD (000 mg/L)	TOC (mg/L)	pH
5/12/95	-	-	-	560	92	-	-	5.7
7/12/95	-	-	-	705	124	-	-	5.8
16/01/96	9.2	6129	467	713	176	-	-	6.7
29/04/96	9.3	9275	698	543	210	100	42425	5.0
30/04/96	7.9	8300	600	662	178	-	29767	5.2
1/05/96	10.3	10175	643	703	248	-	47900	5.0
25/07/96	6.1	6283	478	677	106	42*	21835	4.9
26/07/96	6.3	6000	475	618	97	48*	20683	4.9
AVERAGE	8.2	7694	560	648	154	80	32522	5.4

NOTE
* indicates only a single sample taken.

Table 5-2
Average Pollutant Concentrations in the Product

Date	Total Solids (%)	TKN (mg/L)	Total P (mg/L)	COD ('000 mg/L)	BOD ('000 mg/L)	pH
5/12/95			843			
7/12/95			1013			
16/01/96	20.0	16167	1533			
29/04/96	25.0	21500	1825			
30/04/96	20.0	23667	1583			
1/05/96	19.6	17750	1650			
25/07/96	15.5	15600	1640	207	102*	4.9
26/07/96	13.5	13200	1620		90*	4.8
AVERAGE	18.9	17981	1463	207	-	4.9

NOTE
* indicates only a single sample taken.

Table 5-3
Average Cooling Water Pollutant Concentrations

DATE	TKN (mg/L)	NH3-N (mg/L)	Total P (mg/L)	COD (mg/L)	BOD (mg/L)	TOC (mg/L)	pH
29/04/96	11.0	9.6	0.11	238	120	77	4.9
30/04/96	7.6	6.7	0.03	152		36	6.7
1/05/96	6.9	6.0	0.02	100		28	7.1
25/07/96	17.0	12.0	0.04	763		203	5.9
26/07/96	10.0	7.0	0.04	492		126	4.5
AVERAGE	10.5	8.3	0.05	349.0	120.0	94.0	5.8

Table 5-4
Average Pollutant Mass Delivered in the Raw Feed During Sampling (kg/h)

DATE	Total Solids	TKN	NH_3-N	Total P	COD	BOD	TOC
5/12/95	-	-	-	0.24	39	-	-
7/12/95	-	-	-	0.46	81	-	-
16/01/96	66	4.3	0.3	0.51	126	-	-
29/04/96	253	25.6	1.9	1.54	568	269	117
30/04/96	108	11.4	0.8	0.89	245	-	39
1/05/96	94	9.1	0.6	0.61	227	-	44
25/07/96	135	14.1	1.1	1.53	235	92	49
26/07/96	164	15.5	1.2	1.61	251	140	54
AVERAGE	137	13.3	1.0	0.92	222	167	61

Table 5-5
Average Pollutant Mass Delivered in the Product During Sampling (kg/h)

DATE	Total Solids	TKN	Total P	COD	BOD
5/12/95			0.0		
7/12/95			0.1		
16/01/96	44	3.6	0.3		
29/04/96	152	12.4	1.0		
30/04/96	45	5.4	0.4		
1/05/96	55	5.0	0.5		
25/07/96	145	14.6	1.5	194[1]	96[2]
26/07/96	148	14.4	1.8	-	108
AVERAGE	98	9.2	0.7	194	102

Notes: 1. Not in brief but analysed for completeness.

2. Conducted by QMeat.

Analysis of the data showed that estimation of those pollutant concentrations which had not been analysed was not feasible as:

- no correlations, besides that between raw feed TOC and COD (correlation coefficient 0.95), were found between parameters, and
- average values had high associated standard deviations.

5.2 OPERATIONAL DATA

5.2.1 System

Operational data is detailed in Appendix B. Table 4.6 summarises the average flows, temperatures and pressures experienced during the surveys.

Table 5-6
Average Flows, Pressures and Temperatures Experienced During Sampling

DATE	Steam Press (kPa g)	Steam Flow (kg/h)	Feed Flow (L/min)	Product Flow (L/min)	Feed Temp (°C)	Product Density (kg/L)	Product Temp (°C)	Transfer Flow (L/min)	Cooling Water Temp (°C)
5/12/95	905	832	7	1	-	-	-	-	-
7/12/95	920	832	11	2	-	-	-	-	-
16/01/96	918	918	12	4	-	1.02	52.3	15	-
29/04/96	802	1711	47	13	45	1.05	-	36	22.3
30/04/96	884	887	22	4	48	1.04	-	25	21.8
1/05/96	921	773	15	5	43	1.04	-	18	20.9
25/07/96	781	1945	34	10	47	1.03	36.2*	37	21.0
26/07/96	773	2024	43	15	49.2	1.03	37.2*	48	23.0

NOTE

* indicates manually read temperature.

Some data was estimated in order to allow nutrient removal calculations to be made. Values which have been estimated have been shaded in the Tables in Appendix C and details of the method of estimation are also included in Appendix C.

It should be noted that on the 29/4/96, 25/7/96 and the 26/7/96 the system was purposely run at or near full capacity of the effects. As the capacity of the DEE far exceeds that of the dryer, product flow is directed to waste for safety reasons. During all other sampling surveys, the evaporator system was effectively "idling" at 25% capacity to ensure the product output did not exceed dryer capacity. This is representative of the current system of operation as the system is not normally run at full capacity.

5.2.2 Kill number

Table 4.7 details daily kill numbers on the days of sampling. Due to the impossibility of establishing the exact time of the kills and the significant and variable delay in the wastes from these kills entering the stickwater line, this data was not utilised in the evaluation of the DEE system.

Table 5-7
Daily Kill Numbers.

Date	Ox's/Bullocks	Cows and Heifers	Yearlings	Bulls	Total Cows	Total Pigs
5/12/95	222	285	304	2	813	1312
7/12/95	183	279	194	6	662	1304
16/01/96	75	299	285	1	660	1193
29/04/96	353	483	215	0	1051	1272
30/04/96	391	526	107	19	1043	1261
1/05/96	300	429	186	0	915	1131
25/07/96	51	448	190	27	716	1115
26/07/96	116	406	163	4	689	819

5.3 NUTRIENT MINIMISATION

5.3.1 Condensate quality

Table 4.8 summarises the quality of the condensate effluent calculated after the contribution of the residual cooling water has been taken into account. Appendix D details the methodology for this calculation.

Table 5-8
Average Condensate Effluent Quality

Analyte	29/04/96	30/04/96	1/05/96	25/07/96	26/07/96	Average (mg/L)
TKN	10.4	7.0	5.9	10.5	7.0	8.2
NH_3-N	9.5	6.0	5.0	6.7	4.6	6.4
TP	0.11	0.02	0.02	0.00	0.02	0.03
COD	263	152	100	521	370	281
TOC	80	31	-	120	96	82
BOD	126					126

5.3.2 Overall removal

Table 4.9 summarises the percentage of the nutrient load exiting the system in the effluent. This calculation takes the contribution of the residual cooling water into account.

Table 5-9
Percentage of Influent Nutrient Load Exiting in Condensate

Analyte	29/04/96	30/04/96	1/05/96	25/07/96	26/07/96	Average (%)
TKN	0.13	0.11	0.09	0.15	0.07	0.11
NH_3-N	1.56	1.34	1.19	1.27	0.61	1.20
TP	0.023	0.005	0.004	0.000	0.002	0.01
COD	0.15	0.11	0.06	0.46	0.24	0.20
TOC	0.22	0.14	0.00	0.50	0.29	0.23
BOD	0.15					0.15

5.4 ENERGY CONSUMPTION

5.4.1 Steam

Appendix E details the energy calculations with respect to steam usage during the site surveys. Table 4.10 details the steam energy supplied to the system during each day of sampling.

Table 5-10
Steam Input

Date	Corrected Steam Flow (kg)	Energy (MJ)	Power (MW)
5-Dec-95	8229	21194	981
7-Dec-95	8360	21537	997
16-Jan-96	9108	23460	1086
29-Apr-96	8736	22456	1559
30-Apr-96	7373	18976	879
1-May-96	4446	11530	801
25-Jul-96	9711	25424	2018
26-Jul-96	7514	19670	1501

5.4.2 Electricity

The power readings from the electricity meter are detailed in Appendix E along with the calculation of the rate of power usage:

- 1.16 kW/h on the 25th July (correlation coefficient = 0.98)
- 1.42 kW/h on the 26th July (correlation coefficient = 0.99)

An average value of 1.29 kW/h was used for those days when the electricity meter readings were not available.

5.4.3 Efficiency

The actual energy used by the system in terms of steam was compared with the calculated amount of energy required to vaporise the difference between the feed and product volumes. Table 4.11 shows this calculation and the energy efficiency of the DEE system in terms of the ratio of steam to water evaporated.

Australian manufacturers advise that a single effect evaporator should achieve a 1:1 ratio of steam to water evaporated and that a double effect evaporation should achieve roughly double this.

Table 5-11
Required Energy Input

Date	Feed		Product		Vapour		Calc	Efficiency	Steam
	Mass (kg)	H (kJ/kg)	Mass (kg)	H (kJ/kg)	Mass (kg)	H (kJ/kg)	Req (MJ)	(%)	to Evap
5-Dec	2925	259	392	154	2533	2588	5858	28	3.2:1
7-Dec	376	259	616	154	3151	2588	7275	34	2.7:1
16-Jan	481	259	1451	154	3367	2588	7689	33	2.7:1
29-Apr	10961	259	3473	154	7488	2588	17075	76	1.2:1
30-Apr	7852	259	1492	154	6360	2588	14655	77	1.2:1
1-May	3593	259	1060	154	2533	2581	5771	50	1.8:1
25-Jul	8123	259	2185	154	5938	2567	13476	53	1.6:1
26-Jul	7506	259	2605	154	4901	2567	10978	56	1.5:1

5.5 WATER CONSUMPTION

5.5.1 Cooling tower

The level in the cooling tower reservoir (approximately 4 m x 4 m in surface area) was observed to drop approximately 120 mm when the system was started up. This corresponds to a volume of 190 L.

The rate of overflow from the cooling tower during production, was measured to be 0.88 L/s and this was checked on a number of occasions. There is no overflow when product is being recirculated which occurs until the required product density is reached.

5.5.2 Vacuum pump

Potable water is used to cool the vacuum pump. The system was initially set up with a header tank to allow recirculation. However, it was found that the water reservoir heated rapidly and that insufficient cooling occurred. The vacuum pump cooling water is now a single pass system with water discharged directly to drain.

Water consumption was measured to be 0.4 L/s.

5.5.3 Washdown procedure

The potable water used in the system washdown at the end of the day was calculated from the information on the washdown procedure (refer Section 2.3.3.)

It was calculated that a total of 3.4 m^3 of water is used in this procedure each day.

5.5.4 Flow balance

A flow balance around the DEE system was undertaken and some discrepancies between measured flows were identified. Table 4.12 shows the result of this exercise for the 25th and 26th July 1996.

Table 5-12
Flow Balance (Total Flows, L)

	Parameter/ Flow	25/7/95 (12:30-16:15)	26/7/95 (08:30-12:45)
1.	Condensate No. 1	537	673
2.	Condensate No. 2	0	336
3.	Feed	8273	7650
4.	Transfer	8879	7345
5.	Product	2344	2783
6.	Condensed Steam	9779	7570
7.	Cooling Tower Overflow	12672	9504
8.	Total Evaporated	5929	4867
9.	Calculated C/Tower Overflow	15643	12384
10.	Steam Condensed in No. 1 Effect	606	0
11.	Flow Discrepancy	+23%	+30%

NOTES

1 - 5. Values from system instrumentation.

6. Calculated using specific volume from steam tables at measured pressure and assuming all steam condenses. This value is the corrected steam flow after the calibration error is allowed for.

7. Calculated from measured flowrate of 0.88 L/s.

8. Calculated as difference between volume of Feed (3.) and Product (5.).

9. Calculated as sum of Total Evaporated (8.) and Condensed Steam (6.).

10. Calculated as difference between Feed (3.) and Transfer (4.) volumes.

11. Comparison of estimated (7.) and calculated (9.) Cooling Tower Overflows.

5.6 ECONOMIC EVALUATION

Table 4.13 summarises the results from the Net Present Value (NPV) analysis; the analysis has been undertaken for three internal rates of return (i = 5, 7.5 and 10%) and over two periods of time (N = 10 and 20 years). Details of the calculations and individual capital and operation cost components in Appendix F.

Table 5-13
NPV Analysis ($M)

SYSTEM	DISCOUNT RATE					
	i = 5%		i = 7.5%		i = 10%	
	N = 10 y	N = 20 y	N = 10 y	N = 20 y	N = 10 y	N = 20 y
3000 L/h						
BNR	4.2	5.4	4.0	4.9	3.9	4.5
DEE + Dryer	4.7	5.2	4.7	5.0	4.6	4.8
DEE only	1.1	1.6	1.1	1.4	1.1	1.4
1500 L/h						
BNR	3.6	4.5	3.5	4.1	3.4	3.8
DEE + Dryer	4.2	4.5	4.2	4.4	4.1	4.3
DEE only	0.7	1.0	0.7	0.9	0.7	0.9
750 L/h						
BNR	2.9	3.6	2.8	3.3	2.7	3.1
DEE + Dryer	3.9	4.2	3.9	4.1	3.9	4.0
DEE only	0.5	0.8	0.5	0.7	0.5	0.6

6. DISCUSSION

6.1 INSTRUMENT ERROR

Prior to discussion and analysis of the results, it is necessary to discuss the instrument errors experienced during the sampling surveys as the effect is significant with respect to the accuracy of the results obtained.

- Condensate flows

Values logged for the No. 1 and 2 condensate flows are unusable; during operational hours, flows of approximately zero were recorded and during periods when the system was not operating, values of several litres per minute were recorded.

These flows could therefore not be used in the evaluation of the DEE system. Consequently, the volumes of condensate contributed by the first and second effects could not be determined.

The error may occur as the condensate pumps (P5 and P6, refer Fig. 2.1) are operated at full speed and hence create vacuum conditions in Vapour Heads No. 1 and 2. This causes vapour, which is mostly steam to be removed from the Vapour Heads and discharged through the condensate flow line. The condensate flow meters are specific for liquid flow measurement and not able to measure flows of vapour/liquid streams.

- Steam flows

A second major source of inaccuracy arises from the method used to monitor steam flow. Steam flow readings (4 to 20 mA) are converted to mass flows by use of a coefficient (specific volume) which is specific to a particular steam pressure. As the system is running at lower steam pressures than expected, the coefficient used and steam mass flows calculated, were on investigation, found to be incorrect. This affects the accuracy of water use, power consumption and energy efficiency calculations. A correction factor has been applied to counter this problem as much as possible.

- Cooling water flow

A level of uncertainty is associated with the estimation of the cooling water flows. The overflow of this stream was not provided with flow measurement; CMPS&F arranged with QMeat to install a V-notch weir but this was not implemented. Manual measurements were therefore taken of both the cooling water and vacuum pump overflows, using a container of known volume. Although this method provides a good estimate, continual flow data obtained by the V notch weir would have provided more useful results with a greater feel for the hourly and daily variation in cooling water overflow.

- **Computer data log**

A further problem experienced on site was the fact that the operating computer frequently recorded data under an incorrect time. For example, during the sampling conducted in April/May the computer clock was subsequently found to be one hour forty five minutes fast while during July the clock was forty five minutes fast. Although these discrepancies were noted and accounted for, this fact provides uncertainty over computer data outside of the days when sampling took place.

- **Computer data log**

The final area of unreliability of instrumentation regards the product density data logged by the computer on the 5th, 6th and 7th of December 1995. On these days the QMeat computer recorded the concentrate density as remaining constant at 1.0466 for the entire three day period. This data is unlikely to be correct and was not used in any evaluations. The problem may have occurred through isolation of the side stream on which the density meter is installed and hence monitoring of the same sample throughout the 72 hour period. However this explanation appears unlikely as the product density was observed to change on the computer screen during these dates.

The items identified above represent problems in instrument calibration, instrument installation and/ or the data logging process. CMPS&F undertook the system evaluation on the understanding that all instruments were properly installed and calibrated and hence these errors, which have caused uncertainty with respect to data evaluation, are outside the CMPS&F scope. Nevertheless, CMPS&F have accounted for possible discrepancies and made adjustments when practicable to obtain useful information.

6.2 NUTRIENT MINIMISATION

The results presented in Section 4.3 provide the basis for the evaluation of the evaporator system with respect to nutrient removal efficiency. Tables 4.8 and 4.9 provide evidence supporting the fact that the DEE system succeeds in removing close to 100% of the nutrient and organic loads of the stickwater thus producing high quality effluent.

The main points to emerge from Tables 4.8 and 4.9 are detailed below.

- Less than 0.25% of the stickwater organic and nutrient loads exit the system in the condensate effluent stream. This is true for all analytes tested with the exception of NH_3-N.

  The percentage of influent NH_3-N leaving in the condensate effluent line is more than five times that of the other analytes tested. This result is most likely attributable to the fact that NH_3-N is easily stripped from liquid streams.

  In general, the DEE system is effective in concentrating the nutrient and organic loads in the product stream.

- The DEE system has consistently been shown to produce an effluent stream with nutrient concentrations suitable for river discharge.

  However, despite less than 0.23% of the stickwater organic load leaving in the condensate effluent, COD, BOD and TOC levels of the effluent are too high for river discharge. This is most likely attributable to the stickwater having very high levels of organic pollution relative to nutrient levels and due to entrainment in the absence of baffles in the effects. It is also possible that some contamination of the condensate effluent occurs through the cooling tower system which is located next to a dusty road and which was observed to be contaminated with leaf litter.

  Further treatment of the condensate through biological means would need to be in admixture with sewage or suitable other abattoir waste or by adding limited nutrients as the BOD to P ratio indicates insufficient nutrients to support microbial BOD reduction.

6.3 ECONOMIC EVALUATION

The economic evaluation of the three sizes of treatment systems (DEE including dryer capital costs, DEE without dryer capital costs and BNR) is based on a number of assumptions as outlined below.

- The BNR and DEE treatment systems produce essentially the same quality effluent in respect to nutrients although the BNR effluent would have a lower BOD than the DEE effluent.
- A market exists for the by-product at an average value of $390/t Ds.
- Both the BNR and DEE systems have no residual value after either the 10 year or 20 year period of evaluation.
- Using discount rates of 5%, 7.5% and 10% provides a representative comparison of the treatment methods.
- A large system would have an influent capacity roughly equivalent to the current QMeat evaporator (3000 L/h). The medium sized system was assumed to have half this capacity (1500 L/h) and the small system half this capacity again (750 L/h).
- At some abattoirs, the dryer used in the rendering process will be able to accept the product flow and hence the DEE system could be costed without the capital cost of the dryer. (This situation was based on observations of the situation at QMeat.)

Conclusions of the NPV analysis are detailed below.

- The DEE system is considerably cheaper to operate than the BNR system and consequently becomes more economic at lower discount rates and over greater periods of evaluation.

- The DEE system is less economic that the BNR system if the capital cost of dryer is taken into account. This is with the exception of the twenty year analysis based on a discount rate of 5%.

- If it is assumed that an additional dryer is not required, the evaporator NPV is consistently less than one-third of BNR system NPV.

- The estimated NPV's are not linear with respect to treatment unit capacity. This is due to the fact that the unit sizes are towards the bottom end of the range in which these units are made and consequently a halving in unit size represents only a small reduction in unit cost.

- Although the economic analysis assumed all product was sold for revenue, this assumption has minimal effect on the analysis because even without revenue from product sale the operational expenses of the BNR and DEE are similar and once again the conclusion of the NPV analysis is determined by whether or not the capital costs of the dryer need to be included in the evaluation.

6.4 ENERGY AND WATER CONSUMPTION

6.4.1 Energy

Although considerable variation exists in the results with respect to energy usage, the following conclusions may be reached if the results are considered with respect to the outside factors which were affecting the system operation.

At full capacity an average of 1700 kW of steam energy is supplied to the DEE every hour; 950 kW of steam energy is supplied to the unit every hour when the DEE is running at reduced capacity to allow for the dryer.

- On occasion, the system has been shown to be efficient with respect to energy use. The sampling results suggest that the system is capable of utilising over 70% of energy input to the system in the form of steam.

- Although capable of energy efficiencies of over 70%, the efficiency of the system is highly variable and has been known to drop to under 30%.

- The reduced efficiency on the first 3 days of sampling was attributed to a faulty condensate return valve which was replaced on the 17th of January; performance was noted to improve after this replacement. Such mechanical failures have been reported on other occasions to effect evaporator performance and hence this is not an isolated incident.

- The energy efficiency was considerably higher during the April and May surveys than during July. This variation in results is attributed to scale build-up and consequent fouling resulting from poor cleaning and/ or maintenance of the system. On several occasions, system performance has been noted to decrease due to this fouling of the calandrias; this results in a decrease in heat transfer and hence an increase in steam requirement. In the past, the performance of the system has significantly reduced due to clogging of the calandrias. The problem of fouling was identified in the Literature review (Appendix E) as a common problem of evaporative treatment of waste streams. Sugar mills tend to operate 24 h/d for say 27 days and then clean using various chemicals.

- Although little evidence is provided in the results, it is probable that increased efficiency may be achieved when the system is run at full capacity with a dryer of equal capacity to the effects

6.4.2 Water use

The surveys indicated that an average of 5000 kL of potable water is required by the current system per annum. Over 75% of this volume is attributable to the vacuum pump which uses cooling water on a once-through basis. This analysis does not include water requirements for steam production.

6.5 FLOW BALANCE

The flow discrepancy calculated in Table 4.12 represents a significant proportion (23% and 30%) of each day's total flow. This discrepancy is thought to be attributable to two factors.

- The flow balance ignores the loss of cooling water due to evaporation. It is believed that the evaporative loss of cooling water is significant. particularly in the colder winter months when the moisture gradient between the cooling water and the air passing over the water would be larger. The belief that evaporative loss is significant during the colder months of the year is supported by the fact that considerable volumes of water vapour were observed to be exiting the cooling tower on the 25/7/96.

- The instrument and measurement errors, as discussed in Section 5.1 are believed to contribute to the flow discrepancy.

7. RECOMMENDATIONS/CONCLUSIONS

7.1 GENERAL CONCLUSIONS

The main findings of the DEE system evaluation are detailed below.

- Evaporation is an effective way of producing a high quality effluent low in nutrients and high protein saleable product from rendering plant stickwater.

- The condensate effluent produced from evaporation of stickwater is unsuitable for direct river discharge due to its high BOD concentration; further treatment is required prior to discharge. If the condensate effluent is to be treated biologically then it will need to be treated in admixture with an effluent containing a small amount phosphorus as the level of P in the condensate effluent is insufficient to support biological treatment.

- The DEE system is capable of an energy efficiency of over 70%, however this efficiency was highly variable due to mechanical faults and fouling. If these areas are addressed, a significant improvement in energy efficiency should be realised.

- Potable water usage is roughly 5000 kL/y; this figure can be significantly reduced through addressing the vacuum pump cooling water system at QMeat as this currently represents 75% of potable water use by the DEE.

- The economic viability of the DEE is determined by the capital cost of a dryer. If the purchase of a dedicated dryer can be avoided by the use of existing facilities then stickwater treatment by evaporation is considerably cheaper than BNR.

- Although the NPV analysis has used the assumption that a market can be found for the final product, loss of this revenue does not change the results of the NPV analysis.

- Further studies should not be undertaken without review and correction of the instrument and operational problems identified in this report.

- Further research into the evaporation of stickwater would be beneficial in order to refine the results of this evaluation and confirm those results which are suspect through instrument error.

- Entrainment appears to be occurring within the effects and minimisation of this through would be likely to improve effluent quality

7.2 DOUBLE EFFECT EVAPORATOR OPERATION

A number of operational changes are recommended with respect to the QMeat DEE system. These are as detailed below.

- All instrumentation should be recalibrated to ensure data supplied is correct.

- The coefficient used to convert steam volume to mass flow should be reviewed to ensure it reflects current operational pressures. (The pressure at which the coefficient may be correctly applied is no longer representative of the current operational pressures.)

- A V-notch weir or other flow measuring device should be installed at the overflow point of the cooling tower to provide accurate data on condensate flow from the system.

- The system whereby steam condensate is removed from No. 1 and No. 2 Effects should be reviewed. It is suggested that a steam trap system be installed and pumps be downrated to ensure steam/ vapour is not removed from the system via this line. This will also allow accurate reading from the condensate flow meters.

- A complete clean of the system be undertaken routinely every month. This should prevent a reduction in performance due to fouling.

- A system to prevent the contamination of the cooling tower water reservoir by dust, leaves and bird life be installed.

- It is identified that the vacuum pump cooling water represents an opportunity to significantly reduce potable water use of the system. It is recommended that the vacuum pump cooling water recycle loop be re-established to prevent wastage of this essentially clean commodity. Some form of cascade could be introduced to allow the water to cool.

- The size and capacity of the DEE be reviewed with respect to the dryer capacity.

- Entrainment baffles should be installed in the effects.

7.3 RESEARCH AND DEVELOPMENT

Based on the results of the evaluation of the DEE at QMeat, further research as detailed below is recommended.

- Further sampling and evaluation of the DEE would be beneficial with the system running at capacity after the operation of the system has been revised as per Section 6.1.

- Australian Evaporator suppliers recommend the use of plate evaporators for small scale applications. The current system installed at QMeat is a rising film evaporator and it may be pertinent to undertake a study to evaluate the potential advantages of plate evaporators with respect to rising film evaporators.

- An investigation into the feasibility of utilising existing dryer facilities at abattoirs around Australia should be undertaken. It is likely that this may require the existing dryer facilities to be run 24 h/d but, based on the results of this study, may allow DEE to be an economic alternative to conventional stickwater treatment.

- An investigation/ trial of the addition of suspended solids and or calcium sulphate to the stickwater in order to provide the seed nuclei for prevention of fouling should be undertaken.

- An investigation/ trial of the feasibility of running the evaporator 24 h/d in order to dramatically reduce the energy and water requirements of the system should be undertaken. This may need to be tied in with 24 hour operation of the dryer system.

- An investigation of other methods of drying the evaporator product such as centrifuges to reduce capital costs.

- Research into ways of reducing contaminant entrainment in cooling water.

APPENDIX A

OPERATIONAL AND ANALYTICAL DATA

A.1 DATA TABLES

Tables A1 to A24 contain the analytical and operational data for each of the surveys.

A.2 DATA ESTIMATION

Methods used to estimate data where necessary to allow further system evaluation to be made are as outlined below. Values from the 25th and 26th July 1996 were not used in the data estimation as the plant was run under different conditions and hence were not applicable.

- Steam Pressure (16/1/96)

  Steam pressures from other surveys were averaged in order to estimate the steam pressure on the 16th January. The average pressure was 908 kPa gauge with a standard deviation of 50 kPa (5%).

- Steam Flow (5 & 7/12/95, 16/1/96)

  Steam flows from the 30th April and 1st May were averaged in order to estimate steam flows on those dates with missing data. The average steam flow was 832 kg/h.

- Product Flow (5 & 7/12/95, 16/1/96)

  Product flow rates were estimated on the basis of average feed to product ratios experienced during the other surveys. The average product to feed ratio was 0.31.

Transfer rates and condensate flow readings were not thought to be reliable enough to allow data estimation on the basis of trends and/ or averages.

Analytical results indicated no correlations or trends which could be used to predict pollutant concentrations.

Table A1. Operational and analytical data (5th December 1995).

DATE	TIME	OPERATIONAL DATA								VOLUME EVAPORATED			RAW FEED CONCENTRATIONS								TOTAL POLLUTANT LOAD (kg/h)					
		Steam Pressure (kPa g)	Steam Flow (kg/h)	Raw Feed Flow (l/min)	#1 Condensate Flow (l/min)	#2 Condensate Flow (l/min)	Product Flow (l/min)	Product Density (kg/l)	Transfer Flow (l/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD ('000 mg/l)	TOC (mg/l)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	TOC
5/12/95	0900-1000	783	[redacted]	7	0	3	[redacted]	[redacted]	-	-	-	100	-	-	-	480	61	-	-	5.7	-	-	-	0.21	26	-
	1000-1100	909	[redacted]	8	6	0	[redacted]	[redacted]	-	-	-	100	-	-	-	490	80	-	-	5.8	-	-	-	0.25	40	-
	1100-1200	920	[redacted]	6	0	0	[redacted]	[redacted]	-	-	-	100	-	-	-	500	83	-	-	5.8	-	-	-	0.18	30	-
	1200-1300	928	[redacted]	7	0	0	[redacted]	[redacted]	-	-	-	100	-	-	-	510	83	-	-	5.8	-	-	-	0.22	37	-
	1300-1400	923	[redacted]	4	0	0	[redacted]	[redacted]	-	-	-	65	-	-	-	580	110	-	-	5.8	-	-	-	0.14	27	-
	1400-1500	931	[redacted]	7	0	0	[redacted]	[redacted]	-	-	-	58	-	-	-	680	120	-	-	5.8	-	-	-	0.27	48	-
	1500-1600	938	[redacted]	10	0	0	[redacted]	[redacted]	-	-	-	72	-	-	-	680	110	-	-	5.5	-	-	-	0.41	66	-
	TOTAL	-	5824	2978	374	201	420	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.68	274	-
	AVG	905	832	7	1	0	1.0	-	-	-	-	85	-	-	-	560	92	-	-	5.7	-	-	-	0.24	39	-

Table A2. Analytical data (5th December 1995).

DATE	TIME	HEATING STEAM CONDENSATE						
		TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	TOC (mg/l)	Temperature (°C)	pH
5/12/95	0900-1000	-	-	0.09	31	-	51.4	5.7
	1000-1100	-	-	0.06	28	-	52.1	6.3
	1100-1200	-	-	0.06	54	-	51.2	6.3
	1200-1300	-	-	0.06	28	-	50.5	6.1
	1300-1400	-	-	0.09	28	-	50.5	5.9
	1400-1500	-	-	0.1	46	-	49.1	4.7
	1500-1600	-	-	0.12	35	-	-	5.6
	TOTAL	-	-	-	-	-	-	-
	AVG	-	-	0.08	36	-	50.8	5.8

Table A3. Operational and analytical data (5th December 1995).

DATE	TIME	OPERATIONAL DATA		PRODUCT				TOTAL POLLUTANT LOAD (kg/h)		
		Product Flow (l/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/l)	Total P (mg/l)	Temperature (°C)	Total Solids	TKN	Total P
5/12/95	0900-1000	[redacted]	[redacted]	-	-	710	-	-	-	0.00
	1000-1100	[redacted]	[redacted]	-	-	890	-	-	-	0.00
	1100-1200	[redacted]	[redacted]	-	-	710	-	-	-	0.00
	1200-1300	[redacted]	[redacted]	-	-	820	-	-	-	0.00
	1300-1400	[redacted]	[redacted]	-	-	960	-	-	-	0.08
	1400-1500	[redacted]	[redacted]	-	-	970	-	-	-	0.16
	TOTAL	252	-	-	-	-	-	-	-	0.24
	AVG	0.7	-	-	-	843	-	-	-	0.04

Table A4. Operational and analytical data (7th December 1995).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS								TOTAL POLLUTANT LOAD (kg/h)					
		Steam Pressure (kPa g)	Steam Flow (kg/h)	Raw Feed Flow (L/min)	Product Flow (L/min)	Product Density (kg/L)	Transfer Flow (L/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/L)	NH_3 (mg/L)	Total P (mg/L)	COD ('000 mg/L)	TOC (mg/L)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	TOC
7/12/95	0900-1000	952	[redacted]	27	[redacted]	[illegible]	-	-	-	100	-	-	-	710	130	-	-	5.5	-	-	-	1.14	209	-
	1000-1100	905	[redacted]	7	[redacted]	[illegible]	-	-	-	100	-	-	-	770	130	-	-	5.9	-	-	-	0.30	51	-
	1100-1200	922	[redacted]	7	[redacted]	[illegible]	-	-	-	100	-	-	-	740	130	-	-	5.9	-	-	-	0.30	53	-
	1200-1300	902	[redacted]	7	[redacted]	[illegible]	-	-	-	85	-	-	-	720	120	-	-	5.9	-	-	-	0.31	52	-
	1300-1400	916	[redacted]	7	[redacted]	[illegible]	-	-	-	52	-	-	-	710	130	-	-	5.9	-	-	-	0.30	54	-
	1400-1500	921	[redacted]	10	[redacted]	[illegible]	-	-	-	65	-	-	-	680	120	-	-	5.9	-	-	-	0.39	69	-
	1500-1600	920	832	11	[redacted]	-	-	-	-	-	-	-	-	660	120	-	-	5.3	-	-	-			-
	1600-1700	920	882	11	[redacted]	-	-	-	-	-	-	-	-	650	110	-	-	5.3	-	-	-			-
	TOTAL	-	5824	3836	660	- -	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.75	489	-
	AVG	920	832	11	1.6	-	-	-	-	84	-	-	-	705	124	-	-	5.7	-	-	-	0.46	81	-

Table A5. Analytical data (7th December 1995).

DATE	TIME	HEATING STEAM CONDENSATE						
		TKN (mg/L)	NH_3 (mg/L)	Total P (mg/L)	COD (mg/L)	TOC (mg/L)	Temperature (°C)	pH
7/12/95	0900-1000	-	-	0.07	22	-	49.4	5.7
	1000-1100	-	-	0.07	24	-	51.3	6.2
	1100-1200	-	-	0.07	26	-	49.9	6.1
	1200-1300	-	-	0.17	31	-	49.5	5.8
	1300-1400	-	-	0.06	26	-	46.8	5.5
	1400-1500	-	-	0.06	35	-	47.7	5.4
	1500-1600	-	-	0.07	39	-	-	4.4
	1600-1700	-	-	0.09	24	-	-	5.4
	TOTAL	-	-	-	-	-	-	-
	AVG	-	-	0.08	28	-	49.1	5.6

Table A6. Analytical data (7th December 1995).

DATE	TIME	OPERATIONAL DATA		PRODUCT				TOTAL POLLUTANT LOAD (kg/h)		
		Product Flow (L/min)	Product Density (kg/L)	Total Solids (%)	TKN (mg/L)	Total P (mg/L)	Temperature (°C)	Total Solids	TKN	Total P
7/12/95	0900-1000	[redacted]	[redacted]	-	-	530		-	-	0.00
	1000-1100			-	-	530		-	-	0.00
	1100-1200			-	-	830		-	-	0.00
	1200-1300			-	-	990		-	-	0.07
	1300-1400			-	-	1500		-	-	0.30
	1400-1500			-	-	1700		-	-	0.34
	TOTAL	462	-	-	-	-		-	-	0.70
	AVG	1.3	-	-	-	1013		-	-	0.12

Table A7. Operational and analytical data (16th January 1996).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS								TOTAL POLLUTANT LOAD (kg/h)					
		Estimated Steam Pressure (kPa g)	Estimated Steam Flow (kg/h)	Raw Feed Flow (l/min)	Product Flow (l/min)	Product Density (kg/l)	Transfer Flow (l/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD ('000 mg/l)	TOC (mg/l)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	TOC
16/01/96	0930-1030	920	[redacted]	10	3.9	1.004	14.8	-51	111	60	8.1	5600	420	780	180	-	61	7.0	48	3.3	0.25	0.46	106	-
	1030-1130	920	[redacted]	10	[redacted]	1.012	-	-	-	62	9.7	6400	430	670	160	-	-	6.9	57	3.8	0.25	0.39	94	-
	1130-1230	920	[redacted]	10	[redacted]	1.020	-	-	-	61	10	6500	460	790	190	-	63.2	6.9	58	3.7	0.26	0.46	109	-
	1230-1330	915	[redacted]	14	3.6	1.028	-	-	-	74	9.8	6300	460	770	190	-	61.7	6.9	82	5.3	0.38	0.64	158	-
	1330-1430	917	[redacted]	14	3.9	1.031	-	-	-	72	9.5	6200	480	720	180	-	61.8	6.9	80	5.2	0.40	0.60	151	-
	1430-1530	916	[redacted]	13	3.4	1.032	-	-	-	73	9.2	6100	540	680	180	-	61.4	6.8	70	4.6	0.41	0.52	137	-
	1530-1630	919	932	12	[redacted]	-	-	-	-	-	8.1	5800	480	580	150	-	-	5.4	-	-	-	-	-	-
	TOTAL	-	6424	4905	1554	-	-	-	-	-	-	-	-	-	-	-	-	-	394	25.9	1.96	3.07	756	-
	AVG	918	918	12	3.7	1.021	-	-51	111	67	9	6129	467	713	176	-	61.8	6.7	66	4.3	0.33	0.51	126	-

Table A8. Analytical data (16th January 1996).

DATE	TIME	HEATING STEAM CONDENSATE						
		TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	TOC (mg/l)	Temp	pH
16/01/96	0930-1030	2.5	0.7	5.7	57	-	60	6.0
	1030-1130	5.2	3.1	0.1	35	-	60	7.8
	1130-1230	5.3	3.5	0.3	33	-	60	8.2
	1230-1330	4.8	3.5	0.1	74	-	60	7.8
	1330-1430	5.3	3.5	1.8	24	-	60	7.7
	1430-1530	6.3	4.2	0.1	37	-	60	7.7
	1530-1630	6.4	3.9	0.2	33	-	-	7.0
	TOTAL	-	-	-	-	-	-	-
	AVG	5.1	3.2	0.4	42	-	60	7.5

Table A9. Analytical data (16h January 1996).

DATE	TIME	OPERATIONAL DATA		PRODUCT				TOTAL POLLUTANT LOAD (kg/h)		
		Product Flow (l/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/l)	Total P (mg/l)	Temp	Total Solids	TKN	Total P
16/01/96	0930-1030	3.9	1.004	10	14000	1800	54.9	23	3.3	0.42
	1030-1130	[redacted]	1.012	12	12000	1200	52.5	27	2.7	0.27
	1130-1230	[redacted]	1.020	15	12000	1200	52.5	33	2.7	0.27
	1230-1330	3.6	1.028	26	18000	2000	51.6	56	3.9	0.43
	1330-1430	3.9	1.031	29	21000	2100	51.3	68	4.9	0.49
	1430-1530	3.4	1.032	29	20000	900	50.9	59	4.1	0.18
	TOTAL	1332	-	-	-	-	-	267	21.5	2.1
	AVG	3.7	1.021	20	16167	1533	52.3	44	3.6	0.34

Table A10. Operational and analytical data (29th April 1996).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS									TOTAL POLLUTANT LOAD (kg/h)						
		Steam Pressure (kPa g)	Steam Flow (kg/h)	Raw Feed Flow (L/min)	Product Flow (L/min)	Product Density (kg/l)	Transfer Flow (L/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/l)	NH_3 (mg/L)	Total P (mg/L)	COD ('000 mg/l)	BOD ('000 mg/L)	TOC (mg/L)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	BOD	TOC
29/04/96	1100-1200	826	1292	51	4.2	1.047	24	54	38	92	12	11000	730	900	240	130	65400	-	-	368	34	2.2	2.8	737	399	201
	1200-1300	815	1618	31	9.8	1.047	25	20	49	69	10.3	9900	710	450	270	120	46200	39.1	4.7	193	19	1.3	0.8	507	225	87
	1300-1400	784	1927	47	14.5	1.047	44	6	62	69	8.1	8700	680	420	160	88	29900	45.4	5.0	227	24	1.9	1.2	449	247	84
	1400-1500	784	2007	57	22.6	1.042	52	9	51	60	6.6	7500	670	400	170	60	28200	49.9	5.4	225	26	2.3	1.4	579	204	96
	TOTAL	-	6844	11160	3066	-	8651	-	-	-	-	-	-	-	-	-	-	-	-	1014	102	7.8	6.1	2272	1076	467
	AVG	802	1711	47	12.8	1.045	36	22	50	72	9.3	9275	698	543	210	100	42425	44.8	5.0	253	26	1.9	1.5	568	269	117

Table A11. Analytical data (29th April 1996).

DATE	TIME	COOLING TOWER CONCENTRATIONS							
		TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	BOD (mg/l)	TOC (mg/l)	Temperature (°C)	pH
29/04/96	1100-1200	12	9.7	0.13	250	110	71	-	-
	1200-1300	11	9.5	0.14	220	120	80	20.9	4.8
	1300-1400	11	9.8	0.13	190	130	79	22.6	5.0
	1400-1500	11	9.5	0.03	290	120	76	23.3	4.8
	TOTAL	-	-	-	-	-	-	-	-
	AVG	11	9.6	0.11	238	120	77	22.3	4.9

Table A12. Analytical data (29th April 1996).

DATE	TIME	OPERATIONAL DATA		PRODUCT				TOTALS (kg/h)		
		Product Flow (L/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/L)	Total P (mg/l)	Temperature (°C)	Total Solids	TKN	Total P
29/04/96	1100-1200	3.3	1.047	21	21000	1900	-	41	4.1	0.37
	1200-1300	5.0	1.047	28	25000	2100	-	84	7.5	0.63
	1300-1400	14.5	1.047	28	21000	1700	-	241	18.2	1.48
	1400-1500	17.3	1.042	23	19000	1600	-	240	19.7	1.66
	TOTAL	2402	-	-	-	-	-	607	49.6	4.14
	AVG	10.0	1.045	25	21500	1825	-	152	12.4	1.04

Table A13. Operational and analytical data (30th April 1996).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS								TOTAL POLLUTANT LOAD (kg/h)					
		Steam Pressure (kPa g)	Steam Flow (kg/h)	Raw Feed Flow (l/min)	Product Flow (l/min)	Product Density (kg/l)	Transfer Flow (l/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/l)	NH_3 (mg/L)	Total P (mg/l)	COD ('000 mg/L)	TOC (mg/L)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	TOC
30/04/96	0945-1045	845	781	15.3	2.8	1.032	16	-5	86	82	7.3	6100	540	530	170	26700	42.6	5.1	67	6	0.49	0.5	156	24
	1045-1145	903	722	15.8	3.3	1.036	13	16	63	79	10.1	11000	750	1100	220	43000	43.4	5.1	96	10	0.71	1.0	209	41
	1145-1245	903	1023	34.1	5.0	1.045	22	35	51	85	10.3	11000	690	870	240	26300	48.9	5.0	211	23	1.41	1.8	491	54
	1245-1345	885	907	28.4	5.2	1.050	44	-55	137	82	8.0	8300	570	550	180	35900	51.7	5.0	136	14	0.97	0.9	307	61
	1345-1445	885	910	20.1	5.2	1.051	28	-39	113	74	6.2	7000	520	500	140	24800	52.0	5.4	75	8	0.63	0.6	168	30
	1445-1545	885	979	19.6	5.2	1.049	25	-25	99	74	5.2	6400	530	420	120	21900	51.7	5.4	61	8	0.62	0.5	141	26
	Total	-	5322	7994	1598	-	8882	-	-	-	-	-	-	-	-	-	-	-	646	69	4.8	5.3	1472	236
	Average	884	887	22	4.4	1.044	25	-12	92	79	7.9	8300	600	662	178	29767	48.4	5.2	108	11	0.81	0.9	245	39

Table A14. Analytical data (30th April 1996).

DATE	TIME	COOLING TOWER CONCENTRATIONS						
		TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	TOC (mg/l)	Temperature (°C)	pH
30/04/96	0945-1045	8.1	7.3	0.03	150	39	20.9	5.9
	1045-1145	7.7	6.9	0.04	160	37	21.4	6.6
	1145-1245	7.6	6.9	0.02	150	36	22.1	6.8
	1245-1345	7.6	6.4	0.02	160	35	22.4	6.7
	1345-1445	7.1	6.6	0.02	140	35	22.1	6.8
	1445-1545	7.3	6.3	0.02	150	32	22.2	7.1
	Total	-	-	-	-	-	-	-
	Average	7.6	6.7	0.03	152	36	21.8	6.7

Table A15. Analytical data (30th April 1996).

DATE	TIME	OPERATIONAL DATA		PRODUCT				TOTALS (kg/h)		
		Product Flow (l/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/l)	Total P (mg/l)	Temperature (°C)	Total Solids	TKN	Total P
30/04/96	0945-1045	2.1	1.011	13	13000	1100	-	15	1.6	0.14
	1045-1145	2.6	1.027	14	18000	1100	-	23	2.9	0.17
	1145-1245	2.8	1.032	17	22000	1400	-	29	3.7	0.23
	1245-1345	3.3	1.036	22	28000	1700	-	44	5.5	0.34
	1345-1445	5.0	1.045	25	31000	2100	-	75	9.3	0.63
	1445-1545	5.2	1.050	27	30000	2100	-	83	9.3	0.65
	Total	1257	-	-	-	-	-	269	32.3	2.16
	Average	3.5	1.034	20	23667	1583	-	45	5.4	0.36

Table A16. Operational and analytical data (1st May 1996).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS								TOTAL POLLUTANT LOAD (kg/h)					
		Steam Pressure (kPa g)	Steam Flow (kg/h)	Raw Feed Flow (l/min)	Product Flow (l/min)	Product Density (kg/l)	Transfer Flow (l/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/l)	NH_3 (mg/L)	Total P (mg/l)	COD ('000 mg/L)	TOC (mg/L)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	TOC
1/05/96	1030-1130	921	861	17.2	4.73	1.040	18.6	-8	81	73	9.3	6900	460	410	230	58800	37	6.1	96	7.1	0.47	0.42	237	61
	1130-1230	921	835	16.6	4.73	1.042	18.0	-9	80	71	10.3	9800	590	430	270	40600	43	4.8	102	9.7	0.59	0.43	268	40
	1230-1330	921	764	13.3	4.73	1.044	18.0	-35	100	64	10.8	12000	740	970	240	45100	44	4.4	86	9.6	0.59	0.77	192	36
	1330-1430	921	634	13.9	4.65	1.048	18.0	-29	96	67	10.8	12000	780	1000	250	47100	46	4.5	90	10.0	0.65	0.83	209	39
	TOTAL	-	3094	3658	1130	-	4354.8	-	-	-				-	-	-		-	375	36.4	2.30	2.46	906	176
	AVG	921	773	15	4.71	1.044	18.1	-20	89	69	10.3	10175	643	703	248	47900	43	5.0	94	9.1	0.58	0.61	226	44

Table A17. Analytical data (1st May 1996).

DATE	TIME	COOLING TOWER CONCENTRATIONS						
		TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	TOC (mg/l)	Temperature (°C)	pH
1/05/96	1030-1130	7.3	6.2	0.02	110	42	21.1	7.3
	1130-1230	6.9	6.2	0.02	91	26	20.6	7.2
	1230-1330	6.9	5.9	0.03	89	20	20.9	6.8
	1330-1430	6.6	5.5	0.02	110	22	21.0	7.1
	TOTAL	-	-	-	-	-	-	-
	AVG	6.9	6.0	0.02	100	28	20.9	7.1

Table A18. Analytical data (1st May 1996).

DATE	TIME	OPERATIONAL DATA		PRODUCT				TOTALS (kg/h)		
		Product Flow (l/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/l)	Total P (mg/l)	Temperature (°C)	Total Solids	TKN	Total P
1/05/96	1030-1130	4.7	1.040	13.2	11000	1100	-	37	3.1	0.31
	1130-1230	4.7	1.042	17.3	16000	1300	-	49	4.5	0.37
	1230-1330	4.7	1.044	22	20000	1700	-	62	5.6	0.48
	1330-1430	4.7	1.048	26	24000	2500	-	73	6.8	0.71
	TOTAL	1128	-	-	-	-	-	221	20.0	1.86
	AVG	4.7	1.044	19.6	17750	1650	-	55	5.0	0.47

Table A19. Operational and analytical data (25th July 1996).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS									TOTAL POLLUTANT LOAD (kg/h)						
		Steam Pressure (kPa g)	Steam Flow (kg/hr)	Raw Feed Flow (l/min)	Product Flow (l/min)	Product Density (kg/l)	Transfer Flow (L/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/L)	NH_3 (mg/L)	Total P (mg/l)	COD ('000 mg/L)	BOD ('000 mg/l)	TOC (mg/l)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	BOD	TOC
25/07/96	1130-1200	837	876	6	0.0	1.005	17	-209	309	100																
	1200-1230	788	2098	31	0.0	1.012	20	35	65	100	7.2	7000	500	500	130		24510	47.0	4.9	132	12.8	0.9	0.9	238		45
	1230-1300	771	2098	26	0.0	1.024	32	-20	120	100	6.8	6500	500	810	120		20900	40.2	4.9	107	10.3	0.8	1.3	189		33
	1300-1330	771	2098	36	15.6	1.031	37	-2	59	57	6.4	6600	480	800	110	42	22300	47.3	5.0	140	14.4	1.0	1.7	240	92	49
	1330-1400	771	2098	45	15.6	1.033	55	-23	88	65	5.7	6000	460	710	100		20600	47.0	4.9	153	16.1	1.2	1.9	268		55
	1400-1430	771	2098	45	15.6	1.033	45	0	65	65	5.2	5700	480	610	88		21200	49.9	4.9	139	15.2	1.3	1.6	235		57
	1430-1500	771	2098	45	15.6	1.034	43	3	62	65	5.3	5900	450	630	89		21500	50.5	4.9	142	15.8	1.2	1.7	238		57
	1500-1530	771	2098	43	15.6	1.035	48	-10	74	64																
	Total	-	7781	8273	2345	-	8879	-	-	-	-	-	-	-	-		-	-	-	812	85	6.5	9.2	1409		296
	Average	781	1945	34	10	1.026	2220	-28	105	77	6.1	6283	478	677	106		21835	47.0	4.9	135	14.1	1.1	1.5	235	92	49

Table A20. Analytical data (25th July 1996).

DATE	TIME	COOLING TOWER CONCENTRATIONS							
		Total Solids (%)	TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	TOC (mg/l)	Temp	pH
25/07/96	1130-1200	<0.1	23	17	0.08	1000	283	16.6	6.2
	1200-1230								
	1230-1300	<0.1	19	15	0.04	860	230	20.9	6.2
	1300-1330	<0.1	17	12	0.04	760	209	20.5	6.0
	1330-1400	<0.1	17	12	0.04	753	196	20.6	6.0
	1400-1430	<0.1	16	11	0.04	689	180	18.8	5.6
	1430-1500	<0.1	15	11	0.03	650	169	21.4	5.6
	1500-1530	<0.1	13	8.8	0.02	626	154	21.3	5.6
	Total	-	-	-	-	-	-	-	-
	Average	<0.1	17	12	0.04	763	203	20.0	5.9

Table A21. Analytical data (25th July 1996).

DATE	TIME			PRODUCT							TOTAL POLLUTANT LOAD (kg/h)				
		Product Flow (l/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/l)	Total P (mg/l)	COD ('000mg/l)	BOD ('000 mg/l)	Temp	pH	Total Solids	TKN	Total P	COD	BOD
25/07/96	1130-1200	0.0	1.005												
	1200-1230	0.0	1.012												
	1230-1300	0.0	1.024												
	1300-1330	15.6	1.031	15.9	16000	1800	229	102	35.4	4.9	149.1	15.0	1.7	215	96
	1330-1400	15.6	1.033	16.4	16000	1700	196		33.5	4.9	153.8	15.0	1.6	184	
	1400-1430	15.6	1.033	15.2	16000	1400	190		34.8	4.9	142.5	15.0	1.3	178	
	1430-1500	15.6	1.034	15.2	15000	1600	219		39.6	4.9	142.5	14.1	1.5	205	
	1500-1530	15.6	1.035	14.6	15000	1700	201		37.5	4.9	136.9	14.1	1.6	188	
	Total	2345	-	-	-	-	-				724.9	73.1	7.7	971	
	Average	9.8	1.026	15.5	15600	1640	207		36.2	4.9	145	14.6	1.5	194	96

Table A22. Operational and analytical data (26th July 1996).

DATE	TIME	OPERATIONAL DATA						VOLUME EVAPORATED			RAW FEED CONCENTRATIONS									TOTAL POLLUTANT LOAD (kg/H)						
		Steam Pressure (kPa g)	Steam Flow (kg/hr)	Raw Feed Flow (L/min)	Product Flow (L/min)	Product Density (kg/L)	Transfer Flow (L/min)	#1 Effect (% of Raw Feed)	#2 Effect (% of Raw Feed)	Total (% of Raw Feed)	Total Solids (%)	TKN (mg/L)	NH_3 (mg/L)	Total P (mg/L)	COD ('000 mg/L)	BOD ('000 mg/L)	TOC (mg/L)	Temperature (°C)	pH	Total Solids	TKN	NH_3	Total P	COD	BOD	TOC
26/07/96	0945-1015	773	2108	28	2	1.025	33	-17	111	94	5.4	5300.	420	590	81		17100	50.3	4.6	90	8.9	0.7	1.0	136		29
	1015-1045	773	2007	33	11	1.034	20	39	28	67	6.0	5800	450	430	92		20000	45.5	4.7	118	11.4	0.9	0.8	182		39
	1045-1115	773	2007	48	20	1.034	82	-68	127	59	6.2	6000	460	550	105	48	20600	51.8	4.9	180	17.4	1.3	1.6	305	140	60
	1115-1145	773	2007	50	20	1.034	47	5	54	60	6.7	6000	490	550	110		20700	51	4.9	200	17.9	1.5	1.6	328		62
	1145-1215	773	2007	47	20	1.034	46	1	56	57	6.8	6400	510	810	99		22300	48.8	4.9	192	18.0	1.4	2.3	279		63
	1215-1245	773	2007	49	20	1.034	58	-19	78	59	6.9	6500	520	780	94		23400	47.5	5.1	204	19.2	1.5	2.3	278		69
	Total	-	6072	7650	2783	-	8590				-	-	-	-	-		-	-	-	984	93	7.4	9.7	1507	-	321
	Average	773	2024	43	15	1.032	2863	-10	76	66	6.3	6000	475	618	97		20683	49.2	4.8	164	15.5	1.2	1.6	251	140	54

Table A23. Analytical data (26th July 1996).

DATE	TIME	COOLING TOWER CONCENTRATIONS							
		Total Solids (%)	TKN (mg/l)	NH_3 (mg/l)	Total P (mg/l)	COD (mg/l)	TOC (mg/l)	Temperature (°C)	pH
26/07/96	0945-1015								
	1015-1045	<0.1	12.0	9.1	0.04	572	142	22.6	4.3
	1045-1115	<0.1	11.0	8.0	0.14	531	138	23.1	4.7
	1115-1145	<0.1	9.5	7.1	<0.01	469	127	23.3	4.1
	1145-1215	<0.1	9.1	6.3	<0.01	464	116	23.1	4.5
	1215-1245	<0.1	8.3	6.2	<0.01	423	105	22.7	4.7
	Total	-	-	-	-	-	-	-	-
	Average	<0.1	10.0	7.3	0.09	492	126	23.0	4.5

Table A24. Analytical data (26th July 1996).

DATE	TIME			PRODUCT						TOTALS (kg/h)			
		Product Flow (l/min)	Product Density (kg/l)	Total Solids (%)	TKN (mg/L)	Total P (mg/l)	BOD ('000 mg/l)	Temperature (°C)	pH	Total Solids	TKN	Total P	BOD
26/07/96	0945-1015	1.7	1.025										
	1015-1045	10.9	1.034	13.5	13000	1300		37.8	4.8	88.128	8.5	0.8	
	1045-1115	20.0	1.034	13.2	14000	1300	90	38.3	4.9	158.72	16.8	1.6	108
	1115-1145	20.0	1.034	13.2	12000	1400		32.9	4.7	158.72	14.4	1.7	
	1145-1215	20.0	1.034	13.6	14000	2500		38.5	4.9	163.53	16.8	3.0	
	1215-1245	20.0	1.034	14.2	13000	1600		38.3	5.0	170.74	15.6	1.9	
	Total	5565	-	-	-	-				739.83	72.2	9.0	
	Average	15.5	1.032	13.5	13200	1620		37.2	4.8	147.97	14.4	1.8	

Q MEAT
ABATTOIR GROUP

QUEENSLAND
ABATTOIR
CORPORATION

BRISBANE
Colmslie Road, Cannon Hill
Postal Address: PO Box 20
MORNINGSIDE, QLD. 4170

Phone: (07) 3399 1011
Fax: (07) 3395 6840

9 July 1996 FAX TO: 3233 1649

Mr. Drew McKenzie,
CMPS&F Pty Limited,
66 Eagle Street,
BRISBANE. Q. 4000.

Dear Drew,

Please find enclosed the information you requested in your fax dated 3 July 1996.

1. Capital costs associated with the initial equipment outlay = $35,000
2. Installation and start-up cost = $265,000
3. Additional staff recruitment cost = no extra labour required except for $2/day payment to the two operators who run the unit.
4. Costs resulting from staff training = Estimated at $8,000 which was included in the start-up costs.
5. Electricity unit costs = 8 cents/unit
6. Water unit costs = 91 cents/kl
7. Costs of oxygen/chemicals = oxygen = 29.89 cents/m^3, polymers $223.51/25kg bags approximately 2 bags/day.
8. Cost of equipment hire for existing plant = $1467/month for oxygen storage tank
9. Staffing cost for existing plant = 2 men/day giving a yearly cost of $61,578/year + 40% oncosts
10. Routine maintenance costs on existing plant = Materials $82,596, Labour $73,040 + 40% oncosts
11. Average maintenance costs of evaporators = is not known as it is included in total maintance costs of effluent treatment. At an estimate 2 men for 1 hour/week with $4,000/year materials cost
12. Estimated throughput of the effluent treatment plant before the installation of the evaporator process = 2,500-3,000m^3/day
13. Estimated average throughput after installation = 2,500-3,000m^3/day but there should be a reduction of about 25% in BODs loading
14. Sewerage charges - no sewerage charges exist
15. There is no idea of the effect different size systems will have on the above figures
16. Possible levels of income from sale of end products. If the unit was running at capacity it is estimated that 1.4 tonnes/day of meal would be produced at an average value of $390/tonne.

I trust this has answered all your questions regarding the unit.

Yours sincerely,

R. de LANGE
BY PRODUCTS MANAGER

cc: Mr. Mike Johns (Fax No: 3365 4199)

Tables F.1 to F.3 show the calculation of the costs used to estimated the NPV's of the various options. The actual analysis are provided in Tables F.4 to F.12.

Table F.1

BNR Cost Calculation

Scale Of Operation	Capital Costs ('000 $)				Operational Costs ('000 $/Y)			
	Primary Tank	Bnr Reactors	Secondary Clarifiers	Total	Primary Tank	Bnr Reactors	Secondary Clarifiers	Total
Large (3000 L/h)	100	2130	100	2330	30	163	40	233
Medium (1500 L/h)	100	1948	100	2148	30	108	40	178
Small (750 L/h)	100	1500	100	1700	30	75	40	145

Table F.2

Evaporator Cost calculation

Scale Of	Capital Costs ('000 $)				Operational Costs ('000 $/Y)						
Operation	Dee	Dryer	C/ Tower	Total	Steam	Elect	Water	Dryer Power	Staffing, O& M	Revenue	Total
LARGE (3000 L/h)	400	3600	30	4030	63	0.3	4.55	170	29	179.4	87.45
MEDIUM (1500 L/h)	250	3480	20	3750	31.5	0.2	2.73	85	28	89.7	57.73
SMALL (750 L/h)	140	3450	15	3605	15.75	0.15	1.82	42.5	27	44.85	42.37

Table F.3

Evaporator Cost calculation (Not including dryer capital cost)

Scale Of	Capital Costs ('000 $)			Operational Costs ('000 $/Y)						
Operation	Dee	C/ Tower	Total	Steam	Elect.	Water	Dryer Power	Staffing, O&M	Revenue	Total
LARGE (3000 L/h)	400	30	430	63	0.3	4.55	170	29	179.4	87.45
MEDIUM (1500 L/h)	250	20	270	31.5	0.2	2.73	85	28	89.7	57.73
SMALL (750 L/h)	140	15	155	15.75	0.15	1.82	42.5	27	44.85	42.37

APPENDIX C

LITERATURE REVIEW

STICKWATER EVAPORATOR SYSTEMS

LITERATURE SEARCH

0	18/12/95	Issued for Use	T.F.	K.C.		[signature]	
Rev	Date	Description	By	Chk	Eng	Appd	Appd

TABLE OF CONTENTS

1.0 INTRODUCTION

CMPS&F are currently undertaking a global literature search on the evaluation of the stickwater evaporator process. An interim progress report for the literature search and review has been undertaken in accordance with the agreed timetable between CMPS&F and Meat Research Corporation.

This review is to form the basis of the background information for the evaluation of the stickwater evaporation process. The intention of the literature search is to investigate the variety of stickwater treatments available and the advantages and disadvantages of each. In turn, this literature review is to provide information for the evaporator project and suggestions for any future research which may be of use to the abattoir industry. Furthermore, the information obtained from this search is intended to assist in the analysis and/or verification of the results found during the process evaluation.

On completion, the literature search will be global in nature, utilising our overseas affiliates (Camp Dresser & McKee) and our organisation's access to various international libraries. In addition, library resources Australia wide will be utilised and communication with Australian abattoirs will also obtain information on local experiences and data associated with the stickwater evaporation process.

2.0 METHODOLOGY

The literature search has been in progress for several months and has utilised a number of means for obtaining references. An initial search of CMPS&F internal libraries nation wide was undertaken for literature pertaining to stickwater evaporation processes and other methods of treatment for abattoir wastes.

Following the internal company search numerous external database searches were undertaken. The four most beneficial databases being the following.

- Compendex (an engineering database found on Dialog, all recorded data).
- WasteInfo (found on Orbit, all recorded data).
- Streamflow (data from 1985 to 1995).
- AWWASEEK (Australian Water and Wastewater Association (data from 1964 to 1995))

The primary input search terms included the following:

- Evaporators.
- Wastewater treatment.
- Abattoir/Wastewater.
- Stickwater.

The resulting references were reviewed to determine the suitability of the information. References that were considered appropriate for the project were obtained from Australian libraries, if available.

Further comprehensive searches of the following university libraries, utilising the general library database and CD ROM databases, were also conducted. The university libraries were:

- University of Queensland.
- Queensland University of Technology.
- University of New South Wales.
- Sydney University.

Following the receipt of further references and research on other stickwater treatment options appropriate Australian abattoirs will be contacted in order to obtain information on local operational systems.

In addition to the international database searches, the international aspect of the literature review has been extended to our overseas affiliates who are in the process of obtaining relevant references. Numerous INTERNET searches have also been undertaken over a period of months with the intention of increasing the international search base.

3.0 RESULTS

A number of useful references have been obtained from the various searches however limiting factors were encountered throughout the review, these include:

- The low volume of search matches.
- Delays in obtaining material from libraries due to availability and holding status of the references.
- Majority of close search matches are written in French.

Due to the low number of search matches, the terms of search have been extended to include wastewater treatment of other associated industries, for example treatment of dairy wastewater. Although these associated industries encompass different issues, CMPS&F have found that there is some correlation in the issues of concern.

CMPS&F are still receiving several references from the University of New South Wales, the National library and international sources. It is expected that these documents (which are expected to arrive within the week) will provide further relevant references, thereby providing a means to continue obtaining more information.

4.0 PRELIMINARY INFORMATION

Outlined below are the prominent topics researched to date. The final literature review to be submitted mid-January will further detail the issues discussed below.

Energy Costs

The major drawback of evaporation treatment of wastewater is that it is invariably energy intensive in comparison to other treatment processes. This disadvantage of the system can seriously impact the efficiency and suitability of stickwater evaporators for large scale treatment of wastewater. It has been identified by Jody and Daniels 1990, that this drawback of the system can be significantly reduced with a modification of the basic evaporator system. The modification involves the utilisation of a heat-recovery sub-system which continuously recycles the latent heat of vaporisation to be reused by the system. Such a modification has been reported to make an energy saving of up to 64% (Jody and Daniels 1990).

The applicability and demand for such a modification will become more apparent at the conclusion of our evaluation of energy efficiency and cost efficiency of the evaporator system. The current double effect evaporator system is expected to possess higher efficiencies than reported single effects, therefore it is envisaged that the possibility of a heat-recovery modified system will be of interest to costing scenarios and may present a role in any future research into the stickwater evaporation system.

Evaporator Performance

It has previously been found (Jacobsen 1985) that the performance of evaporator systems is inhibited in some industries due to fouling of the heated surfaces of the evaporator. It was found that enzymatic (proteolytic) treatment of the raw feed improved the capacity of the evaporator by 74% by reducing the susceptibility of the evaporators surfaces to fouling (Jacobsen 1985).

The applicability of enzymatic pretreatment of abattoir raw feed is unknown. As a result CMPS&F are widening their literature search to include any literature available on enzymatic pretreatment of abattoir wastewater.

Water Treatment Quality

The literature search has highlighted the fact that apart from the nutrient content, a major impact of abattoir wastewater results from the bacterial content. As a result of this it is considered important to assess the bacterial status of the concentrate stream. This analysis is considered important for two reasons. Firstly it will determine the ability of the evaporator system to reduce the bacterial content of the stickwater and secondly, such analyses will help determine the applicability of using this stream as a protein source (a significant bacterial content may seriously limit the potential of this product as a protein source). Consequently, CMPS&F feel that undertaking bacterial tests of the raw feed, concentrate and dry product would be valuable. Bacteriological tests were not included in CMPS&F's original proposal however testing may be undertaken in conjunction with the current sampling program for the cost of laboratory and administrative charges.

Stickwater Composition

Our research has highlighted the fact that the efficiency of treating abattoir wastewater with evaporator systems varies greatly depending on the actual composition, flow rate and flow variation of the effluent being treated. As a result, the water quality analysis currently occurring on the evaporator system will assist in determining the suitability of the QMeat effluent for evaporator treatment. Consequently, even if the evaporator system is not appropriate for the QMeat abattoir it is hoped that our research will help other abattoirs with different effluent compositions identify whether an evaporator system is suited to the stickwater feed.

5.0 CONCLUSION

Despite the limitations encountered during the literature review some pertinent references have been found. These references have presented issues for consideration for the current stickwater evaporator process evaluation and for any future stickwater research programs. As a result of completed searches the literature review is currently being extended to encompass other stickwater treatment processes. Issues revealed from this review will be included in the final literature report.

APPENDIX D

NUTRIENT AND COD REMOVAL

Table D.1

Percentage Nutrient/COD Load Removed in the Effluent and Predicted Average DEE Condensate Quality

Date	Analyte	Raw Feed Input	Cooling Water Output	Mass Abs. Or Supp. By C/Water	Nutrient Removal (%)	Average Dee Condensate Quality (Mg/L)
29/04/96	TKN	102	0.14	-0.008	0.13	10.4
	NH3	7.8	0.12	-0.002	1.56	9.5
	TP	6.1	0.001	0.000	0.02	0.1
	COD	2272	3.05	0.320	0.15	263
	BOD	1076	1.54	0.080	0.15	126
	TOC	467	0.99	0.040	0.22	80
30/04/96	TKN	69	0.02	-0.006	0.11	7.0
	NH3	4.84	0.07	-0.008	1.34	6.0
	TP	5.3	0.00	-0.0001	0.01	0.02
	COD	1472	1.65	0.000	0.11	152
	TOC	236	0.39	-0.056	0.14	30.8
1/05/96	TKN	36.4	0.04	-0.006	0.09	5.9
	NH3	2.3	0.03	-0.006	1.20	5.0
	TP	2.46	0.00	0.000	0.004	0.02
	COD	906	0.55	0.000	0.06	100
	TOC	176	0.15	-0.160	-0.003	-1.02
25/07/96	TKN	84.6	0.21	-0.080	0.15	10.5
	NH3	6.5	0.15	-0.066	1.27	6.7
	TP	9.2	0.000	-0.0005	0.000	0.00
	COD	1409	9.43	-2.992	0.46	521
	TOC	296	2.51	-1.032	0.50	120
26/07/96	TKN	92.8	0.10	-0.030	0.07	7.0
	NH3	7.4	0.07	-0.023	0.61	4.6
	TP	9.7	0.000	-0.0002	0.002	0.02
	COD	1507	4.83	-1.192	0.24	370
	TOC	321	1.24	-0.296	0.29	96

Notes

1. The pollutant absorption by the cooling water is equal to the volume of the cooling pond multiplied by the difference between the final and initial pollutant concentration.

2. This evaluation does not take into account the pollutant contamination of the cooling tower reservoir from dust, leaves and bird faeces.

Table D.2

Calculated Nutrient Removal in Product Stream

Date	Analyte	Raw Feed Mass (Kg)	Product Mass (Kg)	Mass Abs/ Supp By 2nd Effect (Kg)	Nutrient Removal (%)
5/12/95	TKN	-	-	-	-
	TP	1.68	0.2	0.29	31
7/12/95	TKN				
	TP	2.75	0.7	1.29	72
16/01/96	TKN	25.9	21.5	6.60	109
	TP	3.07	2.1	-0.99	36
29/04/96	TKN	102	49.6	-2.20	46
	TP	6.1	4.1	-0.33	62
30/04/96	TKN	69	32.3	18.70	74
	TP	5.3	2.2	1.10	62
1/05/96	TKN	36.4	20.0	14.30	94
	TP	2.46	1.9	1.54	138
25/07/96	TKN	84.6	73.1	-1.10	85
	TP	9.2	7.7	-0.11	83
26/07/96	TKN	92.8	72.2	0.00	78
	TP	9.7	9.0	0.33	96

Notes

1. It is assumed that the quality of the first effect contents is essentially constant over the sampling period and similar to the influent quality.

2. The quality of the second effect is assumed to be equal to the product quality.

3. The mass absorption relates to the change in quality of the contents of the second effect and the volume of its contents.

APPENDIX E

POWER USAGE

E.1 Steam

Table E.1 summarises the total steam input and associated energy used during each survey.

Table E.1

Steam Input

Date	Steam Feed				Condensate		Energy	Power
	P	P	Corrected Flow	H	Temp	H	Supplied	Supplied
	(kPa g)	(kPa a)	(kg)	(kJ/kg)	(°C)	(kJ/kg)	(MJ)	(MW)
5-Dec	905	1006	8229	2776	47	200	21194	981
7-Dec	920	1021	8360	2776	47	200	21537	997
16-Jan	908	1009	9108	2776	47	200	23460	1086
29-Apr	802	903	8736	2771	47	200	22456	1559
30-Apr	884	985	7373	2774	47	200	18976	879
1-May	921	1022	4446	2776	43	183	11530	801
25-Jul	781	882	9711	2769	36	151	25424	2018
26-Jul	773	874	7514	2769	36	151	19670	1501

NOTES

1. H = Enthalpy from Steam Tables.
2. It is assumed that all steam condenses.
3. Energy supplied = Steam Mass x (Enthalpy of steam - Enthalpy of condensate)

E.2 Electricity

Tables E.2 and E.3 detail the electricity meter readings taken on the 25th and 26th July 1996.

Table E.2

Electricity Meter Readings (25/7/96)

Time	Power Reading	Power Usage
11:07	2484.70	0.00
11:28	2485.00	0.30
11:38	2485.30	0.60
13:06	2486.30	1.60
13:23	2486.65	1.95
13:40	2487.05	2.35
14:00	2487.50	2.80
14:49	2488.65	3.95
15:25	2489.50	4.80
15:57	2490.30	5.60
16:06	2490.50	5.80

Table E.3

Electricity Meter Readings (26/7/96)

Time	Power Reading	Power Usage
8:05	2494.60	0.00
9:15	2496.20	1.60
9:47	2497.00	2.40
10:34	2498.10	3.50
10:50	2498.50	3.90
11:40	2499.70	5.10
11:50	2499.90	5.30
12:16	2500.50	5.90
12:36	2500.95	6.35
12:40	2501.10	6.50

These values give the following rates:

- 1.16 kW/h on the 25th July ($r^2 = 0.98$)
- 1.42 kW/h on the 26th July ($r^2 = 0.99$)

APPENDIX F

NET PRESENT VALUE ANALYSIS

Table F.4. BNR NPV using a discount rate of 5%.

	LARGE BNR				MEDIUM BNR				SMALL BNR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL SITE COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SITE COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SITE COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	2330	233	2563	2563	2148	178	2326	2326	1700	145	1845	1845
1	0	233	233	222	0	178	178	170	0	145	145	138
2	0	233	233	211	0	178	178	161	0	145	145	132
3	0	233	233	201	0	178	178	154	0	145	145	125
4	0	233	233	192	0	178	178	146	0	145	145	119
5	0	233	233	183	0	178	178	139	0	145	145	114
6	0	233	233	174	0	178	178	133	0	145	145	108
7	0	233	233	166	0	178	178	127	0	145	145	103
8	0	233	233	158	0	178	178	120	0	145	145	98
9	0	233	233	150	0	178	178	115	0	145	145	93
10	0	233	233	143	0	178	178	109	0	145	145	89
11	0	233	233	136	0	178	178	104	0	145	145	85
12	0	233	233	130	0	178	178	99	0	145	145	81
13	0	233	233	124	0	178	178	94	0	145	145	77
14	0	233	233	118	0	178	178	90	0	145	145	73
15	0	233	233	112	0	178	178	86	0	145	145	70
16	0	233	233	107	0	178	178	82	0	145	145	66
17	0	233	233	102	0	178	178	78	0	145	145	63
18	0	233	233	97	0	178	178	74	0	145	145	60
19	0	233	233	92	0	178	178	70	0	145	145	57
10 YEAR TOTAL				4219	10 YEAR TOTAL			3591	10 YEAR TOTAL			2876
20 YEAR TOTAL				5379	20 YEAR TOTAL			4477	20 YEAR TOTAL			3597

Table F.5. BNR NPV using a discount rate of 7.5%.

	LARGE BNR				MEDIUM BNR				SMALL BNR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	2330	233	2563	2563	2148	178	2326	2326	1700	145	1845	1845
1	0	233	233	217	0	178	178	166	0	145	145	135
2	0	233	233	202	0	178	178	154	0	145	145	125
3	0	233	233	188	0	178	178	143	0	145	145	117
4	0	233	233	174	0	178	178	133	0	145	145	109
5	0	233	233	162	0	178	178	124	0	145	145	101
6	0	233	233	151	0	178	178	115	0	145	145	94
7	0	233	233	140	0	178	178	107	0	145	145	87
8	0	233	233	131	0	178	178	100	0	145	145	81
9	0	233	233	122	0	178	178	93	0	145	145	76
10	0	233	233	113	0	178	178	86	0	145	145	70
11	0	233	233	105	0	178	178	80	0	145	145	65
12	0	233	233	98	0	178	178	75	0	145	145	61
13	0	233	233	91	0	178	178	70	0	145	145	57
14	0	233	233	85	0	178	178	65	0	145	145	53
15	0	233	233	79	0	178	178	60	0	145	145	49
16	0	233	233	73	0	178	178	56	0	145	145	46
17	0	233	233	68	0	178	178	52	0	145	145	42
18	0	233	233	63	0	178	178	48	0	145	145	39
19	0	233	233	59	0	178	178	45	0	145	145	37
10 YEAR TOTAL				4049	10 YEAR TOTAL			3461	10 YEAR TOTAL			2770
20 YEAR TOTAL				4883	20 YEAR TOTAL			4099	20 YEAR TOTAL			3289

Table F.6. BNR NPV using a discount rate of 10%.

	LARGE BNR				MEDIUM BNR				SMALL BNR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	2330	233	2563	2563	2148	178	2326	2326	1700	145	1845	1845
1	0	233	233	212	0	178	178	162	0	145	145	132
2	0	233	233	193	0	178	178	147	0	145	145	120
3	0	233	233	175	0	178	178	134	0	145	145	109
4	0	233	233	159	0	178	178	122	0	145	145	99
5	0	233	233	145	0	178	178	111	0	145	145	90
6	0	233	233	132	0	178	178	100	0	145	145	82
7	0	233	233	120	0	178	178	91	0	145	145	74
8	0	233	233	109	0	178	178	83	0	145	145	68
9	0	233	233	99	0	178	178	75	0	145	145	61
10	0	233	233	90	0	178	178	69	0	145	145	56
11	0	233	233	82	0	178	178	62	0	145	145	51
12	0	233	233	74	0	178	178	57	0	145	145	46
13	0	233	233	67	0	178	178	52	0	145	145	42
14	0	233	233	61	0	178	178	47	0	145	145	38
15	0	233	233	56	0	178	178	43	0	145	145	35
16	0	233	233	51	0	178	178	39	0	145	145	32
17	0	233	233	46	0	178	178	35	0	145	145	29
18	0	233	233	42	0	178	178	32	0	145	145	26
19	0	233	233	38	0	178	178	29	0	145	145	24
10 YEAR TOTAL				3905	10 YEAR TOTAL			3351	10 YEAR TOTAL			2680
20 YEAR TOTAL				4512	20 YEAR TOTAL			3815	20 YEAR TOTAL			3058

Table F.7. Evaporator NPV using a discount rate of 7.5%.

	LARGE EVAPORATOR				MEDIUM EVAPORATOR				SMALL EVAPORATOR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL NET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	4030	87.45	4117.5	4117	3750	57.73	3808	3808	3605	42.37	3647.37	3647
1	0	87.45	87.45	83	0	57.73	57.73	55	0	42.37	42.37	40
2	0	87.45	87.45	79	0	57.73	57.73	52	0	42.37	42.37	38
3	0	87.45	87.45	76	0	57.73	57.73	50	0	42.37	42.37	37
4	0	87.45	87.45	72	0	57.73	57.73	47	0	42.37	42.37	35
5	0	87.45	87.45	69	0	57.73	57.73	45	0	42.37	42.37	33
6	0	87.45	87.45	65	0	57.73	57.73	43	0	42.37	42.37	32
7	0	87.45	87.45	62	0	57.73	57.73	41	0	42.37	42.37	30
8	0	87.45	87.45	59	0	57.73	57.73	39	0	42.37	42.37	29
9	0	87.45	87.45	56	0	57.73	57.73	37	0	42.37	42.37	27
10	0	87.45	87.45	54	0	57.73	57.73	35	0	42.37	42.37	26
11	0	87.45	87.45	51	0	57.73	57.73	34	0	42.37	42.37	25
12	0	87.45	87.45	49	0	57.73	57.73	32	0	42.37	42.37	24
13	0	87.45	87.45	46	0	57.73	57.73	31	0	42.37	42.37	22
14	0	87.45	87.45	44	0	57.73	57.73	29	0	42.37	42.37	21
15	0	87.45	87.45	42	0	57.73	57.73	28	0	42.37	42.37	20
16	0	87.45	87.45	40	0	57.73	57.73	26	0	42.37	42.37	19
17	0	87.45	87.45	38	0	57.73	57.73	25	0	42.37	42.37	18
18	0	87.45	87.45	36	0	57.73	57.73	24	0	42.37	42.37	18
19	0	87.45	87.45	35	0	57.73	57.73	23	0	42.37	42.37	17
10 YEAR TOTAL				4739	10 YEAR TOTAL			4218	10 YEAR TOTAL			3949
20 YEAR TOTAL				5174	20 YEAR TOTAL			4505	20 YEAR TOTAL			4159

Table F.8. Evaporator NPV using a discount rate of 7.5%.

	LARGE EVAPORATOR				MEDIUM EVAPORATOR				SMALL EVAPORATOR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL SET COST	TOTAL ANNUAL OPERATION EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SET COST	TOTAL ANNUAL OPERATION EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SET COST	TOTAL ANNUAL OPERATION EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	4030	87.45	4117.45	4117	3750	57.73	3807.73	3808	3605	42.37	3647.37	3647
1	0	87.45	87.45	81	0	57.73	57.73	54	0	42.37	42.37	39
2	0	87.45	87.45	76	0	57.73	57.73	50	0	42.37	42.37	37
3	0	87.45	87.45	70	0	57.73	57.73	46	0	42.37	42.37	34
4	0	87.45	87.45	65	0	57.73	57.73	43	0	42.37	42.37	32
5	0	87.45	87.45	61	0	57.73	57.73	40	0	42.37	42.37	30
6	0	87.45	87.45	57	0	57.73	57.73	37	0	42.37	42.37	27
7	0	87.45	87.45	53	0	57.73	57.73	35	0	42.37	42.37	26
8	0	87.45	87.45	49	0	57.73	57.73	32	0	42.37	42.37	24
9	0	87.45	87.45	46	0	57.73	57.73	30	0	42.37	42.37	22
10	0	87.45	87.45	42	0	57.73	57.73	28	0	42.37	42.37	21
11	0	87.45	87.45	39	0	57.73	57.73	26	0	42.37	42.37	19
12	0	87.45	87.45	37	0	57.73	57.73	24	0	42.37	42.37	18
13	0	87.45	87.45	34	0	57.73	57.73	23	0	42.37	42.37	17
14	0	87.45	87.45	32	0	57.73	57.73	21	0	42.37	42.37	15
15	0	87.45	87.45	30	0	57.73	57.73	20	0	42.37	42.37	14
16	0	87.45	87.45	27	0	57.73	57.73	18	0	42.37	42.37	13
17	0	87.45	87.45	26	0	57.73	57.73	17	0	42.37	42.37	12
18	0	87.45	87.45	24	0	57.73	57.73	16	0	42.37	42.37	12
19	0	87.45	87.45	22	0	57.73	57.73	15	0	42.37	42.37	11
10 YEAR TOTAL				4675	10 YEAR TOTAL			4176	10 YEAR TOTAL			3918
20 YEAR TOTAL				4988	20 YEAR TOTAL			4383	20 YEAR TOTAL			4069

Table F.9. Evaporator NPV using a discount rate of 10%.

	LARGE EVAPORATOR				MEDIUM EVAPORATOR				SMALL EVAPORATOR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL SET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	4030	87.45	4117.45	4117	3750	57.73	3807.73	3808	3605	42.37	3647.37	3647
1	0	87.45	87.45	80	0	57.73	57.73	52	0	42.37	42.37	39
2	0	87.45	87.45	72	0	57.73	57.73	48	0	42.37	42.37	35
3	0	87.45	87.45	66	0	57.73	57.73	43	0	42.37	42.37	32
4	0	87.45	87.45	60	0	57.73	57.73	39	0	42.37	42.37	29
5	0	87.45	87.45	54	0	57.73	57.73	36	0	42.37	42.37	26
6	0	87.45	87.45	49	0	57.73	57.73	33	0	42.37	42.37	24
7	0	87.45	87.45	45	0	57.73	57.73	30	0	42.37	42.37	22
8	0	87.45	87.45	41	0	57.73	57.73	27	0	42.37	42.37	20
9	0	87.45	87.45	37	0	57.73	57.73	24	0	42.37	42.37	18
10	0	87.45	87.45	34	0	57.73	57.73	22	0	42.37	42.37	16
11	0	87.45	87.45	31	0	57.73	57.73	20	0	42.37	42.37	15
12	0	87.45	87.45	28	0	57.73	57.73	18	0	42.37	42.37	14
13	0	87.45	87.45	25	0	57.73	57.73	17	0	42.37	42.37	12
14	0	87.45	87.45	23	0	57.73	57.73	15	0	42.37	42.37	11
15	0	87.45	87.45	21	0	57.73	57.73	14	0	42.37	42.37	10
16	0	87.45	87.45	19	0	57.73	57.73	13	0	42.37	42.37	9
17	0	87.45	87.45	17	0	57.73	57.73	11	0	42.37	42.37	8
18	0	87.45	87.45	16	0	57.73	57.73	10	0	42.37	42.37	8
19	0	87.45	87.45	14	0	57.73	57.73	9	0	42.37	42.37	7
10 YEAR TOTAL				4621	10 YEAR TOTAL			4140	10 YEAR TOTAL			3891
20 YEAR TOTAL				4849	20 YEAR TOTAL			4291	20 YEAR TOTAL			4002

Table F.10. Evaporator(no dryer capital cost) NPV using a discount rate of 5%.

	LARGE EVAPORATOR				MEDIUM EVAPORATOR				SMALL EVAPORATOR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL SET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL SET COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	430	87.45	517.45	517	270	57.73	327.73	328	155	42.37	197.37	197
1	0	87.45	87.45	83	0	57.73	57.73	55	0	42.37	42.37	40
2	0	87.45	87.45	79	0	57.73	57.73	52	0	42.37	42.37	38
3	0	87.45	87.45	76	0	57.73	57.73	50	0	42.37	42.37	37
4	0	87.45	87.45	72	0	57.73	57.73	47	0	42.37	42.37	35
5	0	87.45	87.45	69	0	57.73	57.73	45	0	42.37	42.37	33
6	0	87.45	87.45	65	0	57.73	57.73	43	0	42.37	42.37	32
7	0	87.45	87.45	62	0	57.73	57.73	41	0	42.37	42.37	30
8	0	87.45	87.45	59	0	57.73	57.73	39	0	42.37	42.37	29
9	0	87.45	87.45	56	0	57.73	57.73	37	0	42.37	42.37	27
10	0	87.45	87.45	54	0	57.73	57.73	35	0	42.37	42.37	26
11	0	87.45	87.45	51	0	57.73	57.73	34	0	42.37	42.37	25
12	0	87.45	87.45	49	0	57.73	57.73	32	0	42.37	42.37	24
13	0	87.45	87.45	46	0	57.73	57.73	31	0	42.37	42.37	22
14	0	87.45	87.45	44	0	57.73	57.73	29	0	42.37	42.37	21
15	0	87.45	87.45	42	0	57.73	57.73	28	0	42.37	42.37	20
16	0	87.45	87.45	40	0	57.73	57.73	26	0	42.37	42.37	19
17	0	87.45	87.45	38	0	57.73	57.73	25	0	42.37	42.37	18
18	0	87.45	87.45	36	0	57.73	57.73	24	0	42.37	42.37	18
19	0	87.45	87.45	35	0	57.73	57.73	23	0	42.37	42.37	17
10 YEAR TOTAL ('000)				1139	10 YEAR TOTAL ('000)			738	10 YEAR TOTAL ('000)			499
20 YEAR TOTAL('000)				1574	20 YEAR TOTAL('000)			1025	20 YEAR TOTAL('000)			709

Table F.11. Evaporator(no dryer capital cost) NPV using a discount rate of 7.5%.

	LARGE EVAPORATOR				MEDIUM EVAPORATOR				SMALL EVAPORATOR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL CAPITAL COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL CAPITAL COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL CAPITAL COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	430	87.45	517.45	517	270	57.73	327.73	328	155	42.37	197.37	197
1	0	87.45	87.45	81	0	57.73	57.73	54	0	42.37	42.37	39
2	0	87.45	87.45	76	0	57.73	57.73	50	0	42.37	42.37	37
3	0	87.45	87.45	70	0	57.73	57.73	46	0	42.37	42.37	34
4	0	87.45	87.45	65	0	57.73	57.73	43	0	42.37	42.37	32
5	0	87.45	87.45	61	0	57.73	57.73	40	0	42.37	42.37	30
6	0	87.45	87.45	57	0	57.73	57.73	37	0	42.37	42.37	27
7	0	87.45	87.45	53	0	57.73	57.73	35	0	42.37	42.37	26
8	0	87.45	87.45	49	0	57.73	57.73	32	0	42.37	42.37	24
9	0	87.45	87.45	46	0	57.73	57.73	30	0	42.37	42.37	22
10	0	87.45	87.45	42	0	57.73	57.73	28	0	42.37	42.37	21
11	0	87.45	87.45	39	0	57.73	57.73	26	0	42.37	42.37	19
12	0	87.45	87.45	37	0	57.73	57.73	24	0	42.37	42.37	18
13	0	87.45	87.45	34	0	57.73	57.73	23	0	42.37	42.37	17
14	0	87.45	87.45	32	0	57.73	57.73	21	0	42.37	42.37	15
15	0	87.45	87.45	30	0	57.73	57.73	20	0	42.37	42.37	14
16	0	87.45	87.45	27	0	57.73	57.73	18	0	42.37	42.37	13
17	0	87.45	87.45	26	0	57.73	57.73	17	0	42.37	42.37	12
18	0	87.45	87.45	24	0	57.73	57.73	16	0	42.37	42.37	12
19	0	87.45	87.45	22	0	57.73	57.73	15	0	42.37	42.37	11
10 YEAR TOTAL ('000)				1075	10 YEAR TOTAL ('000)			696	10 YEAR TOTAL ('000)			468
20 YEAR TOTAL('000)				1388	20 YEAR TOTAL('000)			903	20 YEAR TOTAL('000)			619

Table F.12. Evaporator(no dryer capital cost) NPV using a discount rate of 10%.

	LARGE EVAPORATOR				MEDIUM EVAPORATOR				SMALL EVAPORATOR			
	CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES			CAPITAL COSTS	OPERATIONAL EXPENSES		
YEAR	TOTAL CAPITAL COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL CAPITAL COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE	TOTAL CAPITAL COST	TOTAL ANNUAL OPERATIONAL EXPENSES	ESTIMATED TOTAL ANNUAL COST	DISCOUNTED VALUE
0	430	87.45	517.45	517	270	57.73	327.73	328	155	42.37	197.37	197
1	0	87.45	87.45	81	0	57.73	57.73	54	0	42.37	42.37	39
2	0	87.45	87.45	76	0	57.73	57.73	50	0	42.37	42.37	37
3	0	87.45	87.45	70	0	57.73	57.73	46	0	42.37	42.37	34
4	0	87.45	87.45	65	0	57.73	57.73	43	0	42.37	42.37	32
5	0	87.45	87.45	61	0	57.73	57.73	40	0	42.37	42.37	30
6	0	87.45	87.45	57	0	57.73	57.73	37	0	42.37	42.37	27
7	0	87.45	87.45	53	0	57.73	57.73	35	0	42.37	42.37	26
8	0	87.45	87.45	49	0	57.73	57.73	32	0	42.37	42.37	24
9	0	87.45	87.45	46	0	57.73	57.73	30	0	42.37	42.37	22
10	0	87.45	87.45	42	0	57.73	57.73	28	0	42.37	42.37	21
11	0	87.45	87.45	39	0	57.73	57.73	26	0	42.37	42.37	19
12	0	87.45	87.45	37	0	57.73	57.73	24	0	42.37	42.37	18
13	0	87.45	87.45	34	0	57.73	57.73	23	0	42.37	42.37	17
14	0	87.45	87.45	32	0	57.73	57.73	21	0	42.37	42.37	15
15	0	87.45	87.45	30	0	57.73	57.73	20	0	42.37	42.37	14
16	0	87.45	87.45	27	0	57.73	57.73	18	0	42.37	42.37	13
17	0	87.45	87.45	26	0	57.73	57.73	17	0	42.37	42.37	12
18	0	87.45	87.45	24	0	57.73	57.73	16	0	42.37	42.37	12
19	0	87.45	87.45	22	0	57.73	57.73	15	0	42.37	42.37	11
10 YEAR TOTAL ('000)				1075	10 YEAR TOTAL ('000)			696	10 YEAR TOTAL ('000)			468
20 YEAR TOTAL('000)				1388	20 YEAR TOTAL('000)			903	20 YEAR TOTAL('000)			619