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Influence of operating conditions on protein recovery from blood in the meat industry

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Abstract

A critical issue for the meat industry is the loss of nutrients to stickwater in blood processing, which also leads to an increased environmental burden. This project was aimed at providing the red meat industry with information to maximise the efficiency of blood processing through a two-step research program, namely, development of a mass balance around the blood decanter at the site Tallows and Protein Meals, and evaluation of the efficiency of various methods for nutrient recovery from stickwater resulting in a lower effluent discharge load.

A mass balance around the decanter was developed based on flow composition and operational conditions, and was used as a tool for analysing performance. It was found that the majority of the total nitrogen in stickwater was in organic form, and the loss of gross protein to stickwater at the site was estimated as 1 tonne per 140 tonne raw blood daily intake, equivalent to 5.6% of the protein processed.

After laboratory centrifugation, the effect of using membrane filtration, pH alteration or heating on stickwater was tested for effective nutrient removal. Ultrafiltration removed 40% of the COD and 40% of the total Kjeldahl nitrogen (TKN), while reducing the pH removed 24% of the COD and 10% of the TKN.

Despite the stickwater having been processed through a decanter, over 50% of the residual TKN could be removed by a simple settling step. Samples of stickwater from two other major abattoir blood processing plants indicated similar deficiencies in the decanter processing. It is recommended that consideration be given to installation of a settling tank to allow solids precipitation before any further treatment.

Executive summary

During the manufacture of blood meal from blood by steam coagulation and centrifugation there is considerable loss of protein, phosphate and COD in the blood stickwater which ends up being discharged to waste treatment at great cost. The aims of this project were to gather information on the characteristics of the influent and effluent streams from the blood process, and so evaluate the efficiency of the current blood processing operation at a rendering plant, and to assess the effects of various methods on nutrient recovery from the stickwater.

A mass balance around the decanting centrifuge was developed based on flow composition and operational conditions, and was used as a tool for analysing performance. The loss of gross protein to stickwater at the rendering plant was approximately one tonne dry weight blood meal per 140 tonne raw blood daily intake, equivalent to 5.6% of the protein processed.

Simple settling of blood stickwater achieved significant reductions in nutrient levels with chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN) and total phosphorus (TP) being reduced by 35%, 53% and 16%, respectively. Observation of the blood stickwater from two major abattoirs also indicated considerable carryover of solids.

Investigation of the effects of various methods on further nutrient recovery from the fraction of stickwater after simple settling showed that

- ultrafiltration was the most effective, giving 40% reduction of COD and TKN, microfiltration gave markedly lower nutrient retention, 7% of COD and 8% of TKN;
- considerable reduction of nutrients was achieved by lowering pH, with the maximum COD and TKN removals being 24% and 19% from the dissolved fraction of stickwater at pH 4.8 over the pH range 3.8-8.5;
- no nutrient reductions in stickwater were obtained by further heat treatment at 75-100 ºC; and
- none of the methods tested could effectively reduce TP, the maximum removal being 7% by ultrafiltration.

It is recommended that

- a range of other samples of blood stickwater be collected and similarly analysed to ensure these findings are normal;
- a settling tank is installed to allow solids precipitation before any further treatments are applied;
- pH adjustment is a simple and practical means for the meat industry to apply for further reduction of nutrient level in the dissolved fraction of stickwater, without the need for major capital investment;
- although of the treatment methods evaluated in this study ultrafiltration gave the highest nutrient removal, economic factors, such as higher capital cost, operating and maintenance cost associated with the high membrane fouling potential of stickwater need to be considered;
- and further investigation be undertaken at lab scale and/or small pilot plant scale to optimise the conditions, and determine the necessary operating and economic data.

Contents

1 Background

The Australian red meat industry produces in excess of 3 million tonnes of beef and sheep carcasses (hot standard carcass weight) per annum. This will produce between 180 and 200 million litres of blood. It is a nutrient source which is recovered by rendering plants to make value-added by-products. In most rendering operations, blood is processed by direct steam injection to an in-line coagulator, followed by a decanting centrifuge for liquid and solid separation. The solids are dried to produce blood meal. A considerable amount of nutrients can be lost in the liquid fraction of the coagulated blood, called blood stickwater, contributing to the pollutant load of the wastewater, and also constituting a loss of resources [1]. Factors affecting the efficiency of blood processing include blood properties (e.g., age, solids content) and operating conditions (e.g., feed rate, coagulating temperature, cleanliness of decanter).

Chemical oxygen demand (COD) is used as a gross overall indicator of organic polluting material in wastewater streams, and nitrogen and phosphorus are important measurements of nutrient content. Blood is a significant source of nitrogen due to its high protein content. Total Kjeldahl nitrogen (TKN) is a measure of the sum of organic and ammonia nitrogen. Organic nitrogen can be converted by microbial activity to ammonium ion and then to nitrate [2]. Blood has a high phosphorus content which occurs almost solely as phosphates [3]. The characteristics of stickwater from different abattoirs or rendering plants may vary greatly, depending on factors such as source of raw blood, and processing efficiency [4]. Phosphates (TP) are a major cause of algal blooms. Biological removal of COD and nitrogen is easier than phosphate removal although they all come at a cost.

2 Project Objectives

The project was aimed at gathering information on the characteristics of the influent and effluent of the blood process at a Victorian rendering plant, the efficiency of the current blood processing operation, and the effects of various additional processes on nutrient recovery from stickwater. Nutrient recovery would result in a reduction in COD, TKN and TP in the effluent going to waste.

The main objectives of the research were to:

- develop a mass balance around the decanter at the rendering plant and use it as a tool for analysing the efficiency of a blood process;
- evaluate the effects of various methods for recovering nutrients from stickwater (i.e., settling, adjustment of pH and temperature, and membrane filtration) in terms of COD, TKN and TP removals.

3 Methodology

3.1 Chemical Analysis

Five stickwater samples were supplied by the rendering plant on five occasions representing conditions at low (e.g., 6.0-6.2 tonne/h), normal (e.g., 6.4-6.7 tonne/h) and high (e.g., 7.0-7.2 tonne/h) feed rates through the coagulator/decanter. This was to examine the variation of blood stickwater quality at different feed rates, and hence to develop a representative mass balance around the decanter installed at the rendering plant. One whole blood and five blood stickwater samples were collected from the rendering plant and transported in the cold to RMIT University laboratory, and were stored at 4 ºC before analyses and tests.

Analytical methods used in this research were validated through trials with various abattoir blood samples at the commencement of the project. Chemical oxygen demand (COD), total nitrogen (TN), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) were analysed in blood samples using standard HACH colorimetric methods with associated HACH analytical regents. Organic nitrogen was determined by the difference of the TKN values before and after ammonia nitrogen removal. The method used for removing ammonia nitrogen from samples was adapted from standard methods [5].

Total solids (TS), total dissolved solids (TDS) and their ash contents were analysed using standard methods [5]. Moisture content of a blood meal (product) was measured as 6.2%. TDS and fixed solids (ash) were analysed for stickwater as these analyses were of special value to the rendering plant due to them considering further processing of stickwater using evaporation.

3.2 Blood Stickwater Treatment Tests

The effects of pH, temperature, microfiltration (MF) and ultrafiltration (UF) on nutrient recovery from stickwater (in terms of COD, TKN and TP removals) were evaluated. These methods were chosen due to their low impact on the properties of the recovered blood meal and its subsequent uses.

The effect of pH was studied by adjusting the stickwater to pH 5.5, 4.8 and 3.8 using concentrated hydrochloric acid (HCl), and to 8.5 using 6N sodium hydroxide solution (NaOH). After pH adjustment, the stickwater was centrifuged at 2500 rpm for 1 min to accelerate the precipitation of solids, and the COD, TKN and TP of the supernatant was measured. As a control, an untreated stickwater sample was also centrifuged under the same conditions for comparison.

As blood processing plants use a range of temperatures for blood coagulation, the effect of temperature was studied by heating stickwater samples to 75, 88 and 100 ºC, and then holding for 5 min at each temperature. The samples were cooled to room temperature and centrifuged as described above.

Recovery of stickwater nutrients by microfiltration (MF) and ultrafiltration (UF) was evaluated using a 0.22 µm hydrophilic polyvinylidene fluoride (PVDF) MF membrane and a 100 kDa hydrophilic polyethersulphone (PES) UF membrane in a laboratory scale stirred-cell MF/UF system at typical operating pressures for MF (80 kPa) and UF (150 kPa), at room temperature.

4 Results and Discussion

4.1 Mass Balance around Decanter

4.1.1 Characteristics of Influent and Effluent

A summary of the characteristics of the influent and effluent streams of the decanter at the rendering plant is presented in Table 1, all analytical results can be found in Tables 4 to 8 of the Appendix. The rendering plant noted that at high processing rates through the decanter there was solids carryover, and it was observed that the quality of the stickwater decreased with increasing feed rate, indicating that decanter efficiency decreased at higher feed rates. This was borne out by the variations of TS, COD and TN from their average values of 15%, 26% and 27%, respectively.

Table1 Characteristics of the influent and effluent streams.

Parameters	Whole blood	Stickwater*
COD, mg/L	291,000	11,342
Total nitrogen as N mg/L	20,600	1,203
Total phosphate as P mg/L	260	247
Total solids wt.%	11	1.2
Total dissolved solids mg/L	-	8,237
Total Suspended Solids (TSS) wt. % (by	-	0.38
Total Fixed Solids (ash, dry basis), wt.%	2.53	-
Dissolved Fixed Solids (ash), mg/L	-	4,354
Dissolved Volatile Solids, mg/L (by	-	3,88

* Average value of five collections.

4.1.2 Mass Balance

A mass balance (Figure 1) around the decanter was developed based on the results in Table 1, and a typical blood feed rate of 6500 kg/h. Other data used for the mass balance calculation appear in Table 9 in the Appendix. It can be seen that the losses of TS, COD and TN to stickwater accounted for 10%, 3.7% and 5.6% of the input, respectively, and about 90% of the TP input went to the stickwater. That is, the coagulation/decanter process recovers 90%, 96.3%, and 94.6% of the total solids, COD and total nitrogen, respectively, as blood meal but only 10% of the phosphate.

A comparison of the characteristics of the site's stickwater with those found in the literature or for stickwater water samples collected from other abattoirs (Table 10 in the Appendix) suggests that the blood dewatering process at the rendering site was running reasonably efficiently at the time of the five sample collections [4, 6-9]. However, there was still considerable nutrient loss to the stickwater, which would be worth recovering for productivity enhancement and reduction of environmental impact.

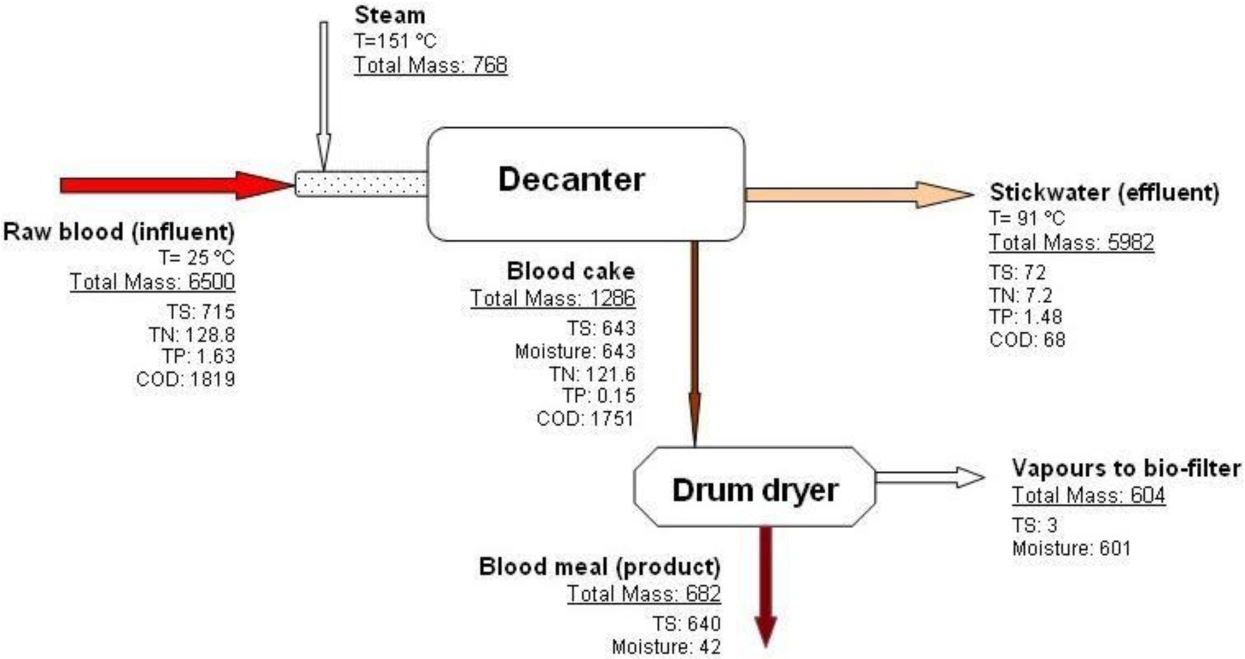

Figure 1 Diagram of mass flow around decanter at the rendering site (unit: kg/h)

4.2 Gross Protein in Stickwater

Samples 4 and 5 were analysed to determine how much of the TN in blood stickwater was in organic form (Table 2). Organic nitrogen and ammonia nitrogen accounted for 85% and 8.7% of the TN, respectively. It was noticed that the ammonia nitrogen for Sample 4 was markedly higher than Sample 5 (Table 7 and 8 in the Appendix), this may have because Sample 4 had been stored longer unrefrigerated after collection at the rendering site allowing greater breakdown of the organic nitrogen to ammonia.

Gross protein in stickwater was calculated as 7938 mg/L, as gross/crude protein = TKN x 6.25 [10]. Hence, the loss of gross protein to stickwater at the rendering site was approximately one tonne per day, calculated on the basis of 140 tonne raw blood daily intake, i.e., 5.6% of the protein intake is not recovered.

Table 2 Summary of average values of nitrogen concentrations for Samples 4 and 5.

Parameters	Stickwater
TN, as N mg/L	1,350
TKN, as N mg/L	1,270
Organic Nitrogen, as N mg/L	1,152
Ammonia Nitrogen, as N mg/L (by calculation)	118

4.3 Investigation of Various Treatment Methods for Recovering Nutrients

For all stickwater samples, a significant amount of solids settled out after collection. For Samples 4 and 5, the average reductions of COD, TKN and TP due to settling were 35%, 53% and 16%, respectively (Table 3). This implies that a simple settling step would result in removal of more than half the protein in blood stickwater with a consequential 35% reduction in the COD of the waste. The study was therefore directed at investigating the effects of various methods on further recovery of organic materials from settled stickwater, where the remaining nutrients would be mostly in dissolved form. Therefore, it should be noted that subsequent discussion of nutrient removals is in comparison with the fraction after settling, i.e., the dissolved fraction of stickwater.

Table 3 Comparison of COD, TN and TP before and after settling of stickwater *

Parameter	Non-settling**	Settled	Reduction after settling (%)
COD, mg/L	11,500	7475	35%
TKN, as N mg/L	1,270	602	53%
TP, as P mg/L	259	217	16%

* Average value for Samples 4 and 5, individual results can be found in Table 11 in the Appendix.
**Each sample was mixed thoroughly by shaking for 5 min to represent the non-settled state.

4.3.1 Effect of pH

The pH of the untreated stickwater (Sample 4) was 6.9. Figure 2 shows the COD, TKN and TP removals at various pH values. Higher removals of COD, TKN and TP were achieved at lower pH, with greatest removals at pH 4.8, where 24% of COD and 19% of TKN were removed. The greater removal of COD and TKN at pH 4.8 was most likely due to the pH being close to the isoelectric point of the proteins [11], leading to their precipitation. It was interesting to note that at pH 8.5 there was a small increase rather than removal of COD and TKN, suggesting that the organic materials such as proteins were slightly more soluble in the higher pH environment than at lower or neutral pH, and so were more difficult to coagulate and remove by centrifugation.

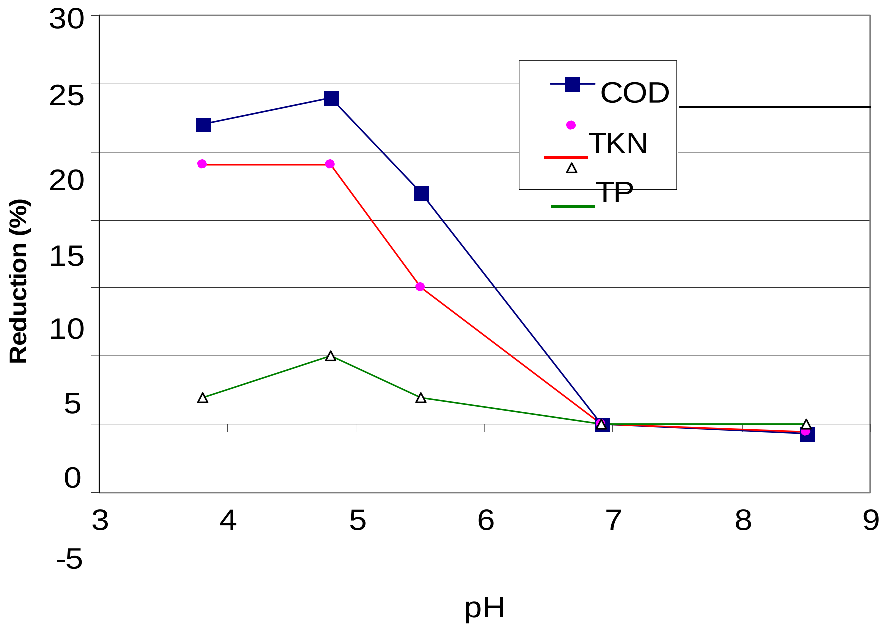

Figure 2 COD, TKN and TP reductions at various pH values for Sample 4.

4.3.2 Effect of Temperature

The removals of COD, TKN and TP at all three temperatures 75, 88 and 100 ºC, were less than 1% compared with the non-heated sample, indicating no further protein removal occurred over the range temperature tested. This result suggests that heating the stickwater to 85-95 ºC during the steam-coagulation and decanting processes removed all the proteins which can be denatured over the range 75-100 ºC, and that no further heat-related protein removal is possible.

4.3.3 Effect of Membrane Filtration

Up to 40% of the COD and TKN were removed by the UF membrane, whereas MF gave only 7-8% reduction for these parameters (Figure 3). The higher COD and TKN removal/rejection rates by UF were attributed to its tighter structure with average pore size of 0.01µm, leading to more effective retention of organics with larger molecular weight (i.e., > 100 kDa) compared with the looser MF membrane. The removal of TP by MF or UF was less than 10%, with UF giving considerably higher removal than MF. This indicates that the majority of the phosphorus in stickwater is in dissolved form and a nanofiltration or reverse osmosis membrane would be required for its removal.

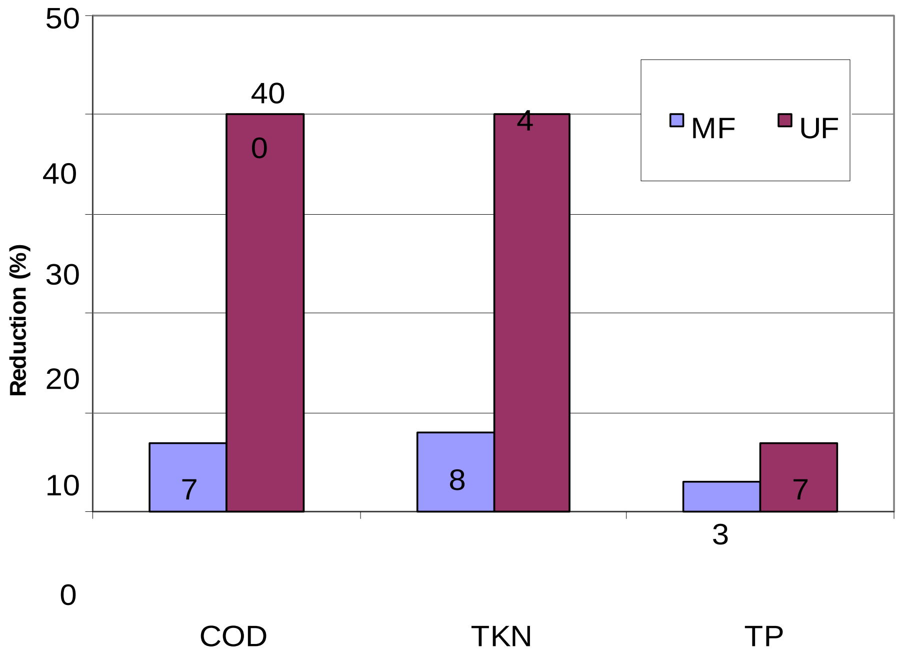

Figure 3 Comparison of COD, TKN and TP removals by MF and UF for Sample 4.

5 Success in Achieving Objectives

The two-stage research work was carried out in line with the original plan. Although there was a delay in getting samples on two occasions due to operational problems at the site, the overall progress met the timeframe well. One extra sample collection was undertaken compared with our original plan of 4 collections to allow a more representative mass balance around the decanter at. In addition to the planned tests, the effectiveness of membrane filtration was evaluated. Overall, the planned and added work was completed under the requirements of the plan, and the goals were achieved accordingly.

It should be acknowledged that the technical manager of the rendering site provided great assistance in supplying samples and technical information during this work.

6 Benefits to the Meat Industry

The mass balance developed in this work is a useful tool for the red meat industry to gain a better understanding of blood processing, and hence help to develop better process management. The work also provides the red meat industry with some important information on the physico-chemical properties and treatability of blood stickwater, thus providing a basis for further development of feasible methods for nutrient recovery/waste minimisation. The work highlighted the necessity of operating the decanter such that there is no carryover of solids which were evident in blood stickwater samples from two major abattoirs blood stickwater and from the rendering site.

7 Conclusions

1. A mass balance around the site decanter was developed using the data from five stickwater samples, which were collected at various feed rates (e.g., 6000 to 7200 kg/h). The average losses of TS, COD and TN to stickwater accounted for 10%, 3.7% and 5.6% of the input, respectively, but approximately 90% of the TP input remained in the stickwater.
2. It was confirmed that the majority of the stickwater nitrogen content (85% TN) was in organic form rather than as ammonium ion.
3. The daily loss of gross protein to stickwater was estimated as one tonne (dry weight) per140 tonne of liquid blood processed.
4. Simple settling of stickwater achieved significant reduction of nutrients with the COD, TKN and TP being reduced by 35%, 53% and 16%, respectively.
5. Investigation of the effects of various methods on nutrient recovery from settled blood stickwater showed that ultrafiltration (UF) was the most effective, giving 40% reduction of COD and TKN. Microfiltration (MF) gave markedly less nutrient retention, 7% of COD and 8% of TKN.
6. Considerable reduction of nutrients was achieved by lowering pH, with the maximum COD and TKN removals being 24% and 19% from settled stickwater at pH 4.8 over the pH range 3.8-8.5.
7. No further nutrient reductions in settled stickwater were obtained by heat treatment at 75-100 ºC.
8. None of the methods tested could effectively reduce TP, the maximum removal being 7% by UF.

8 Recommendations

1. Consideration be given to installation of a settling tank after the decanter to allow solids precipitation before any further treatment due to the significant reduction in the amount of nutrients in the stickwater by a simple settling step (>50% TKN).

2. After stickwater settling, considerable nutrient removal i.e., 24% COD, and 19% TKN can be achieved by simply lowering the pH to 4.8. This would be a simple and practical means for meat industries to apply, without the need for major capital investment.

3. The solids generated by settling or other treatment steps may be pumped back to the decanter, or to an additional centrifuge if the decanter is already overloaded, for nutrient recovery and reduction in waste discharge load.

4. Incorporation of a cooling system with the settling facility would be beneficial to the application of a membrane process such as UF, as commercially available polymeric membranes may not be suitable for direct filtration of the stickwater at temperatures > 90 ºC. Most commercially available polymeric UF membranes operate below 50 ºC.

5. Although of the treatment methods evaluated in this study UF gave the highest nutrient removal, economic factors, such as higher capital cost, operating and maintenance cost associated with the high membrane fouling potential of stickwater need to be considered in the selection of a feasible process for stickwater treatment. Further investigation can be undertaken at lab scale to optimise the conditions, and/or small pilot plant scale to determine the necessary operating and economic data.

9 Bibliography

[1] MLA (2007) Environmental Best Practice Guidelines for the Red Meat Processing Industry (ISBN: 9781741910834)

[2] Russel, J.M., Cooper, R.N., Lindsey, S.B. (1993) Soil denitrification rates at wastewater irrigation sites receiving primary-treated and anaerobically treated meat-processing effluent. *Bioresource Technol*., 43, 41-46

[3] Aguilar, M.I, Saez, J., Llorens, M., Soler, A., Ortuno, J.F. (2002) Nutrient removal and sludge production in the coagulation-flocculation process. *Water Res*. 36, 2910-2919

[4] Mittal G.S. (2004) Characterization of the effluent wastewater from abattoirs for land application, *Food Review International*, 20 (3), 229-256

[5] Standard Methods for the Examination of Water and Wastewater. 20th Edition, APHA, AWWA and USEPA.

[6] MLA (1997) Meat Technology – Information Sheet, Environmental Control in the Rendering Industry, reprinted November 2006.

[7] Fane A.G. Abdul J., D'Souza N.D, Madaeni S. Parameshwaran K. & Ye Y. (2004) Membrane Technologies for Meat Processing Waste Streams, MLA Final Report (ISBN: 1740366085)

[8] Green A. (2007) Blood Stickwater and Decanter Balance, 4th year Chemical Engineering Research Project Report, RMIT University

[9] Laird F. (2005) The Environmental Effects of Blood in the Meat Industry, 4th year Chemical Engineering Research Project Report, RMIT University

[10] Couillard D., Zhu S. (1993), Thermophilic aerobic process for the treatment of slaughterhouse effluents with protein recovery. *Environ. Pollution* 79, 121-126

[11] Butler J.E., Hamilton W.C., Sasser R.G., Ruder C.A., Hass G.M., Williams R.J. (1982), Detection and partial characterization of two bovine pregnancy-specific proteins. *Biology of Reproduction* 26, 925-933

10 Appendix

Table 4 Analysis results for Sample 1 (11/5/2007 feed rate 6.4 tonne/h)

Parameters	Stickwa ter		
	Analysis	Analysis	Average
Chemical Oxygen Demand (COD),	10,000	12,000	11,000
Total Nitrogen (TN), as N mg/l	86	84	85
Total Phosphorus (TP), as P mg/l	19	19	19
Total Solids (TS) , wt. %	1.1	1.2	1.1
Total Dissolved Solids (TDS),	8,266	8,800	8,533
Total Suspended Solids (TSS) wt.	-	-	0.3
Dissolved fixed solids (ash), mg/l	4,064	4,190	4,127
Dissolved volatile solids, mg/l (by	-	-	4,406

Table 5 Analysis results for Sample 2 (19/6/2007, feed rate >7.0 tonne/h)

Parameters	Whole blood			Stickwater		
	Analysis 1	Analy sis	Averag e	Analysis 1	Analysis 2	Averag e
Chemical Oxygen Demand (COD),	290,000	292,00	291,00	13,000	15,000	14,000
Total Nitrogen (TN), as N mg/l	19,900	21,300	20,600	1,120	1,150	1,135
Total Phosphorus (TP), as P mg/l	265	25	260	242	254	248
Total Solids (TS) , wt. %	10.8	11.2	11	1.36	1.36	1.36
Total Dissolved Solids (TDS),	-	-	n/a	7,040	8,866	7,953
Total fixed solids (ash, dry basis),	2.5	2.56	2.53	-	-	n/a
Total Suspended Solids (TSS) wt.	-	-	n/a	-	-	0.56
Dissolved fixed solids (ash), mg/l	-	-	n/a	4,120	4,266	4,193
Dissolved volatile solids, mg/l (by	-	-	n/a	-	-	3,760

Table 6 Analysis results for Sample 3 (4/7/2007, feed rate 6.0 tonne/h)

Parameters	Stickwa ter		
	Analysis	Analysis	Average
Chemical Oxygen Demand (COD),	7,960	8,200	8,080
Total Nitrogen (TN), as N mg/l	72	74	73
Total Phosphorus (TP), as P mg/l	22	22	22
Total Solids (TS) , wt. %	0.9	1.0	1
Total Dissolved Solids (TDS),	8,500	8,900	8,700
Total Suspended Solids (TSS) wt.	-	-	0.1
Dissolved fixed solids (ash), mg/l	4,540	4,630	4,585
Dissolved volatile solids, mg/l (by	-	-	4,115

Table 7 Analysis results for Sample 4 (24/7/2007, feed rate 7.2 tonne/h).

Parameters	Stickwater		
	Analysis	Analysis	Average
Chemical Oxygen Demand (COD), mg/L	11,800	12,400	12,100
Total Nitrogen (TN), as N mg/L	1,400	1,350	1,375
Total Kjeldahl Nitrogen (TKN), as N mg/L	1,357	1,334	1,346
Organic Nitrogen, as N mg/L	1,135	1,147	1,141
Ammonia Nitrogen, as N mg/L (by calculation)	-	-	205
Total Phosphorus (TP), as P mg/L	294	298	296
Total Solids (TS) , wt. %	1.22	1.24	1.23
Total Dissolved Solids (TDS), mg/L	9,500	7,700	8,600
Total Suspended Solids (TSS) wt. %	-	-	0.37
Dissolved fixed solids (ash), mg/L	4,220	4,420	4,320
Dissolved volatile solids, mg/L (by calculation)	-	-	4,280

Table 8 Analysis results for Sample 5 (25/7/2007, feed rate 6.7 tonne/h).

Parameters	Stickwater		
	Analysis	Analysis	Average
Chemical Oxygen Demand (COD), mg/L	11,000	10,800	10,900
Total Nitrogen (TN), as N mg/L	1,350	1,300	1,325
Total Kjeldahl Nitrogen (TKN), as N mg/L	1,185	1,200	1,193
Organic Nitrogen, as N mg/L	1,170	1,155	1,163
Ammonia Nitrogen, as N mg/L (by calculation)	-	-	30
Total Phosphorus (TP), as P mg/L	223	221	222
Total Solids (TS) , wt. %	1.18	1.2	1.19
Total Dissolved Solids (TDS), mg/L	9,033	6,400	7,717
Total Suspended Solids (TSS) wt. %	-	-	0.42
Dissolved fixed solids (ash), mg/L	4,360	4,520	4,440
Dissolved volatile solids, mg/L (by calculation)	-	-	3,277

Table 9 Data used for mass balance calculation.

Parameters	Value	Information
Average raw blood intake	140,000	Rendering site
Time to process (hr/day)	21.5	Rendering site
Feed rate (kg/hr)	6,500	Rendering site
Moisture in blood cake (%)	50	Rendering site
Moisture in product blood meal	6.2 (6 to 7)	Analysed by RMIT (Rendering site)
Steam pressure (kPa)	500	Rendering site
Overall product yield (%)	10.5 (10-11 depending upon raw	Rendering site
TS loss at Drum Dryer (% TS of	0.4	
Density of influent (kg/L)	1.0	
Density of effluent (kg/L)	1	

Table 10 Comparison of rendering site blood processing effluent and those found in literature.

Reference	COD	TN (mg/L)	Phosphorus	TSS (%)
Rendering plant	8,080-14,000	730-1,135	195-248	0.13-0.56
MLA data [6]	15,000-	1,200-	75-150	0.2-2
Fane *et al* [7]	100,000	2,000-	200-300	2
Mittal [4]	150,000	16,500	183	-
Green [8]	-	1,900-	-	-
Laird [9]	174,800	23,050	280	-

Table 11 Reductions of COD, TKN and TP before and after settling for Samples 4 and 5.

Parameters	Sample 4			Sample 5		
	Non-settled	Settled	Reduction	Non-settled	Settled	Reduction
COD, mg/L	12,100	6,750	47.3%	10,900	8,575	21.3%
TKN, as N mg/L	1,346	536	60.2%	1193	668	44%
TP, as P mg/L	296	218	26.3%	222	216	2.7%