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Assessment of Hydrocyclones for Fat Removal from Meat Processing Wastewater Streams

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Executive Summary

The normal operation of meat processing plants produces a warm wastewater with naturally high levels of COD, total nitrogen and phosphorus, total suspended solids and fats, oils and grease. The removal of these excessive fats, oils and grease is important prior to subsequent biological treatment. Furthermore, as the industry moves towards more sophisticated biological treatment processes, the removal of oil and grease (O&G) is becoming increasingly important in order to avoid severe operational problems. The industry also faces increasingly stringent regulations for waste disposal, together with intensification of meat processing.

To date, the most effective and most widely used process for achieving near complete removal of O&G from raw wastewater has been dissolved air flotation. Hydrocyclones are another technology that may offer significant benefits for the removal of O&G from wastewater streams and have recently been introduced to the meat processing industry in Australia, with approximately 5 – 6 units being installed in the past 18 – 24 months.

Early indications are that hydrocyclones can achieve excellent O&G removal and recovery and are relatively cost-effective in comparison with other technologies. However, there is little published evidence to demonstrate their actual performance on meat processing wastewater. Therefore, Meat & Livestock Australia (MLA) engaged GHD to undertake project PRENV.022 – *Assessment of Hydrocyclones for Fat Removal from Meat Processing Wastewater Streams*.

Over the period 26 May – 11 June 2003, GHD conducted site inspections and trials of hydrocyclone installations operating at three (3) Australian meat processing plants. The results from this program have demonstrated that the single-stage hydrocyclone is an effective O&G removal technology for the meat processing industry. Furthermore, by comparison of the sampling program results with literature reports on other O&G removal technologies, this study has also demonstrated that the single-stage hydrocyclone can achieve a similar treatment standard for meat processing wastewater as other non-chemical, non-biological technologies.

The results from GHD's sampling program also indicated that there was little additional benefit (in terms of suspended solids removal) to be gained from a two-stage hydrocyclone (i.e. de-oiling hydrocyclone, followed by de-sanding hydrocyclone). Additional solids removal/recovery due to the de-sanding stage was found to be in the order of 10%. This result is based upon trials at only one reference site.

An examination of the capital, operating and maintenance costs of hydrocyclones, in comparison to other technologies also showed them to offer significant advantages. In particular, the specific cost (i.e. $ per tonne removed) for suspended solids and O&G removal in hydrocyclones is significantly lower than the traditional dissolved air flotation O&G treatment technology.

The key benefits of hydrocyclones can thus be summarised as:

- Achieves high degree of contaminant removal, particularly suspended solids and O&G;
- No chemical additives required;
- Very short residence time (in the order of seconds) and consequently very small footprint;
- High quality fat-rich stream (i.e. low FFA concentration due to short residence time), which may have a recoverable economic value as a high-grade tallow;
- Minimal operating and maintenance costs; and
- Very capital cost-effective, particularly in specific terms of $ per tonne of suspended solids and O&G removed.

The results of the sampling program and the comparison with other technologies is summarised below.

Summary of Single-stage Hydrocyclones versus Other O&G Removal Technologies

	Save-all	DAF (with no chemicals)	DAF	IAF	IC-Sep	H/cyclone
Treatment Efficiency						
COD/BOD	20 – 25%	30 – 40%	30 – 90%	~ 80%	~ 90%	10 – 30%
SS	50 – 60%	50 – 65%	50 – 90%	~ 90%	~ 98%	15 – 60%
O&G	50 – 80%	60 – 80%	80 – 95%	~ 95%	~ 99%	40 – 90%
Nitrogen	-	-	-	-	-	10 – 25%
Phosphorus	-	-	-	-	-	10 – 25%
Capital Costs						
$ / tonne COD removed / year	$870	$1,360	$970	$950	$1,390	$1,090
$ / tonne TSS removed / year	$850	$1,950	$2,260	$1,980	$3,070	$1,270
$ / tonne OG removed / year	$1,900	$4,760	$6,420	$5,610	$9,220	$2,540
Operating & Maintenance Costs						
$ / tonne COD removed / year	$8.40	$7.70	$7.10	$7.90	$6.80	$7.10
$ / tonne TSS removed / year	$8.20	$11.00	$16.60	$16.40	$15.00	$8.30
$ / tonne OG removed / year	$18.40	$26.90	$47.10	$46.70	$44.90	$16.60

1. Introduction

1.1 Background

The normal operation of meat processing plants produces a warm wastewater with naturally high levels of COD, total nitrogen and phosphorus, total suspended solids and fats, oils and grease. The removal of these excessive fats, oils and grease is important prior to subsequent biological treatment. Furthermore, as the industry moves towards more sophisticated biological treatment processes (e.g. covered anaerobic lagoons and biological nutrient removal), the removal of oil and grease (O&G) is becoming increasingly important in order to avoid severe operational problems. The industry also faces increasingly stringent regulations for waste disposal, together with intensification of meat processing [1].

To date, the most effective and most widely used process for achieving near complete removal of O&G from raw wastewater has been dissolved air flotation (DAF). However this has certain disadvantages, including the recovery of a sloppy fat float, containing less than 6wt% solids, and reduced effectiveness at higher wastewater temperatures [1].

Hydrocyclones are another technology that may offer significant benefits to the meat processing industry for the removal of O&G from wastewater streams. Hydrocyclones were originally developed for use in the oil and gas industry, and have since found many applications in a wide range of industries, including the food processing and dairy industries. However, hydrocyclone technology has only recently been introduced to the meat processing industry in Australia, with approximately 5 – 6 units being installed in the past 18 – 24 months. This represents an unusually rapid take-up of "new technology" in the industry [1].

Early indications are that hydrocyclones can achieve excellent O&G removal and recovery and are relatively cost-effective in comparison with other technologies. However, there is little published evidence to demonstrate their actual performance on meat processing wastewater. Therefore, Meat & Livestock Australia (MLA) has engaged GHD to undertake project PRENV.022 – *Assessment of Hydrocyclones for Fat Removal from Meat Processing Wastewater Streams* [1]. The key aim of the study is to provide the industry with the necessary data to facilitate the rapid and successful implementation of hydrocyclone technology.

1.2 Scope

Over the period 26 May – 11 June 2003, GHD conducted site inspections and trials of hydrocyclone installations operating at three (3) Australian meat processing plants. The purpose of these visits was to collect relevant information regarding each plant, such as:

- Kill processes and rates;
- Water consumption and wastewater production;
- Detailed information regarding the hydrocyclone installations:
  - location and application;
  - design conditions, drawings and operating manuals;
  - existing performance data;
  - chemical and power requirements; and
  - operation and maintenance requirements.

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[1] Meat & Livestock Australia (June 2002). *Terms of Reference: PRENV.022 – Assessment of Hydrocyclones for Fat Removal from Meat Processing Wastewater Streams.*

- Information regarding the subsequent biological treatment systems and the effect of the hydrocyclone operation of these systems

During the site visits, GHD also conducted extensive sampling of the hydrocyclone units. At each site, samples were taken over a period of two (2) days to fit with the many variations of meat processing plant operations. These samples were subsequently sent to a NATA-registered laboratory for analyses.

This report provides a summary of the data collected at the three meat processing plants. It also provides a comparison of the hydrocyclone technology with conventional O&G removal technologies, such as DAF and save-alls. This comparison examines both the technical performance of these technologies, as well as their cost-effectiveness in various areas:

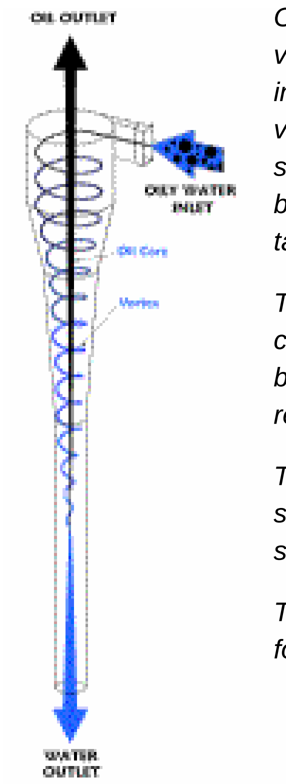
- Capital cost;
- Operating costs:
  - power;
  - chemicals; and
  - operational man hours per day.
- Maintenance costs; and
- Value of recovered fat.

GHD's documentation of these trials and our comparison of hydrocyclones with other O&G removal technologies will assist with the rapid and successful implementation of this technology at the industry level.

2. Hydrocyclone Technology

2.1 Physical Principles

The three hydrocyclone installations inspected by GHD in the course of this project were all supplied by Spinifex Australia Pty Limited (now known as Ultraspin Pty Limited). For information, shown below is an extract from Spinifex literature explaining the operation of the de-oiling hydrocyclone.



Oily water enters the unit through a tangential inlet. The flow is directed into a vortex. As the flow is forced down the liner it takes up a helical form along the inner walls. It is accelerated in the concentric reducing section to the high velocities required to create the strong centrifugal forces that promote rapid separation. These velocities are maintained along the liner, frictional losses being off-set by a gradual reduction in cross-sectional area throughout the tapered section.

The water moves to the wall of the separator and is removed at the downstream clean water outlet. Oil is drawn into the low-pressure core and, by applying a backpressure to the treated water outlet, flows back up the separator to be removed at the upstream outlet orifice.

The vortex and reverse flowing core extend down into the tail section of the separator, increasing the residence time and allowing smaller, slower separating oil & grease droplets to migrate to the core.

The centrifugal force inside the Spinifex Separator is more than 1000 times the force of gravity [2].

Hydrocyclones can also be used for dedicated solids removal (i.e. de-sanding hydrocyclone). The physical separation principle is exactly the same as illustrated above, but the treated water exits at the top of the unit, whilst the heavier solids-rich stream exits from the bottom of the unit. One of the plants inspected during this study had a two-stage hydrocyclone installation, which included de-oiling hydrocyclones, followed in series by de-sanding hydrocyclones.

Typically, a single-stage de-oiling hydrocyclone installation consists of the following units, as shown in Figure 1:

- Floating skimmer (optional) on effluent pit/tank for suction of feed;
  - systems can also be designed to treat full wastewater, requiring no skimmer for side stream removal.
- Debris strainer (typically 3mm) and feed pump (typically 450 – 500 kPa discharge):
  - low flow systems – air-operated diaphragm pump;
  - medium flow system – helical rotor pump; or

[2] Prendergast, G., *Product Recovery and Effluent Treatment Systems for the Meat Industry – General Recommendations*, Spinifex Australia, Mitcham.

  - high flow system – low-shear centrifugal pump.

- De-oiling hydrocyclone for O&G removal;
- Centrate returns to effluent pit/tank for further biological treatment or can be recycled;
- O&G discharges to heated/insulated (optional) collection tank;
- Water underflow from collection tank returns to effluent pit/tank for further biological treatment; and
- Recovered O&G decanted from collection tank.

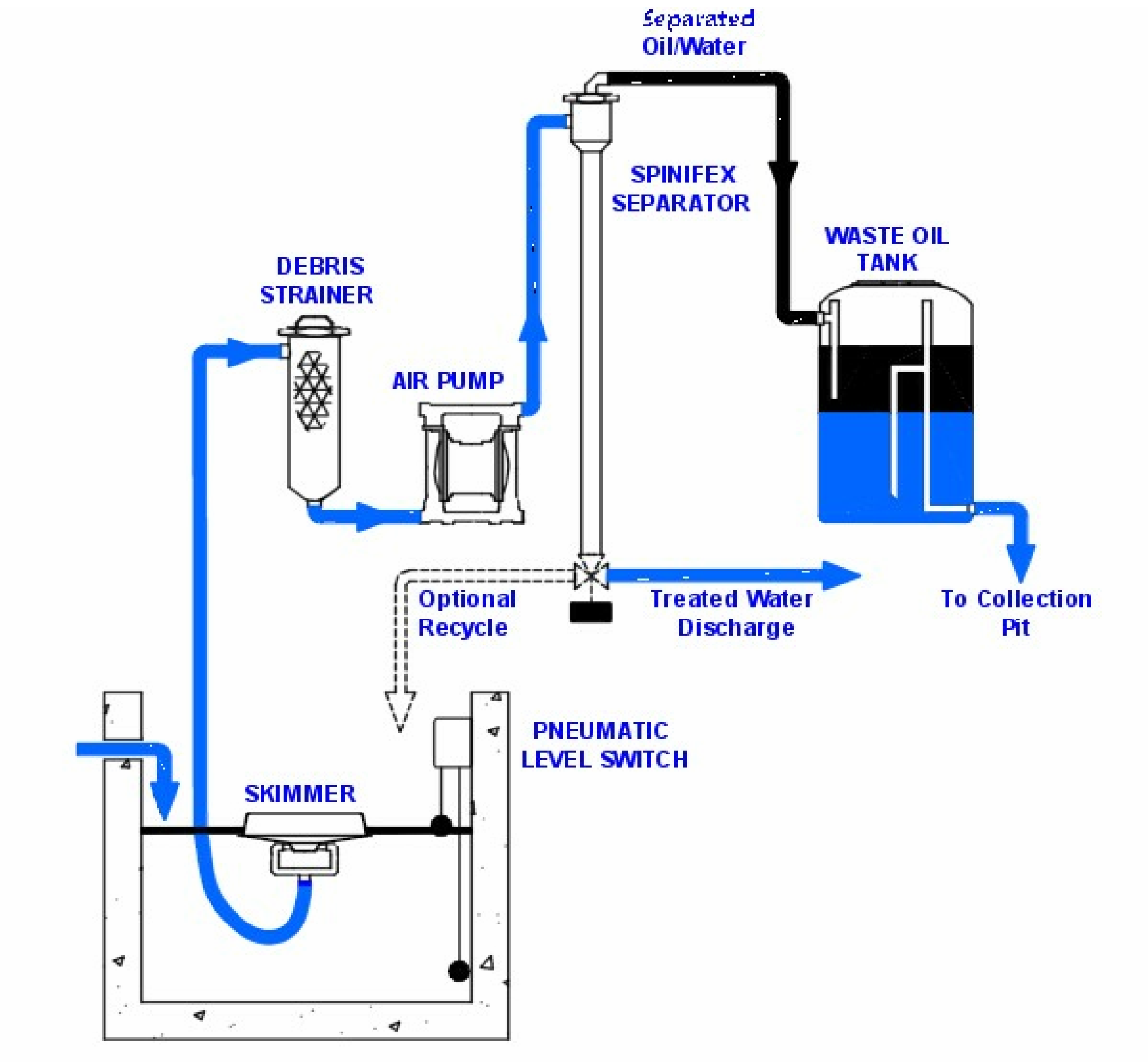


Figure 1 Typical Single-stage De-oiling Hydrocyclone Installation [3]

[3] http://www.ultraspin.com.au/images/Module_system2.jpg, accessed on 25/7/2003.

2.2 Design Considerations

The Ultraspin web site (http://www.ultraspin.com.au/index.htm) provides a significant amount of information regarding the design and operation of hydrocyclones. Outlined below is a summary of the material provided on the web site, plus information gathered from further discussions between GHD and Ultraspin representatives, and GHD's own experience in designing and implementing O&G removal system (inc. hydrocyclone installations).

Some of the critical factors to be considered in the design of a hydrocyclone O&G removal system are [4]:

- Design of separator:
  - The design of a hydrocyclone is based on optimum geometric ratios (e.g. separator length, diameter, orifice sizes, and taper angles) to achieve maximum separation efficiency.
- Fluid properties:
  - Temperature
    The viscosity of water falls as the temperature rises. This allows oil droplets to move more easily through the water phase, thereby producing better separation. Therefore increased temperature results in improved separation performance.
    Note that for some separators (e.g. DAFs), higher temperatures can reduce separation efficiency, as noted above.
  - Droplet size
    Separation efficiency is highest with large oil droplets. Very small droplets are more difficult to separate. The nature of the process or application determines the size of the oil droplets and the client or system designer can do little to promote larger oil droplets.
    Shown in Figure 2 below is Ultraspin's assessment of hydrocyclone separation efficiency versus oil droplet size, as compared against other O&G removal technologies.
  - Density difference
    The efficiency of separating oil from oil/water mixtures is dependant on the difference in density between the contaminant and the water. The separation efficiency increases as the difference in density increases.
  - Inlet concentration
    For a constant droplet size distribution, increasing inlet oil concentration will not change the separation efficiency. However, in practice it is found that the droplet size increases with inlet oil concentration and hence the efficiency also increases.
- Method of operation:
  - Flow rate
    The strength of the centrifugal forces induced in the separator is a function of the flow rate. At low flows, forces are insufficient to establish the required vortex and little separation can take place. Once the vortex is established, the efficiency rises rapidly. Whilst most separators (e.g. plate packs, DAF) decrease in efficiency as flow increases, for hydrocyclones, separation efficiency increases gradually as a function of flow rate. The upper flow limit is generally set by the pressure available between inlet and reject streams.

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[4] http://www.ultraspin.com.au/learning%20centre.htm, accessed on 25/7/2003.

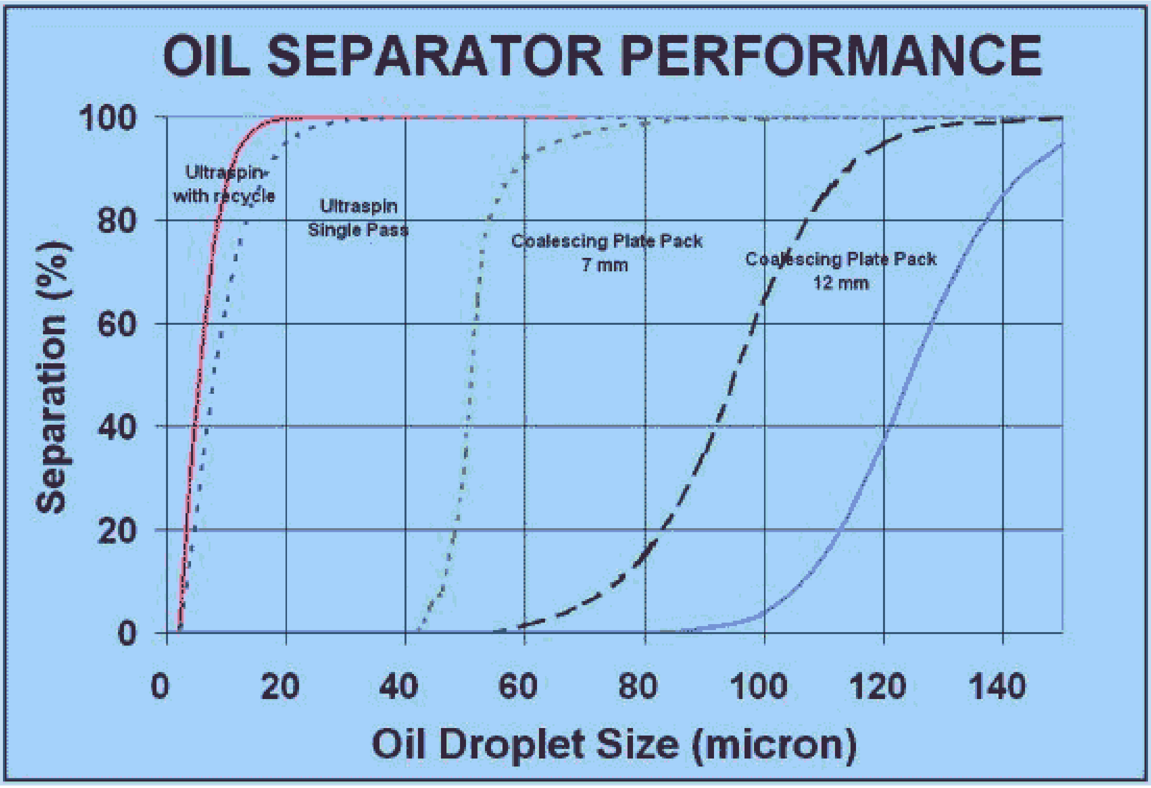

Figure 2 Oil Separator Performance [5,6]

– Reject ratio
  The reject ratio is the ratio of the fatty stream leaving the hydrocyclone to the feed flow rate. This is an important parameter in the operation of the separator. Typical reject ratios are from 1% to 20%, subject to design requirements.
  A minimum reject ratio exists below which the efficiency of the separator can be impaired. This depends on the size of the reject orifice. A high reject ratio does not affect the performance of the separator. However, it leads to excess water in the separated oil stream and can result in unnecessary recirculation of water. Hence, the optimum reject ratio is just above the minimum reject ratio.

– Centrate recycle
  A proven method of increasing the power of separation is to recycle part or all of the treated centrate back to the inlet for further treatment. This can greatly improve separation efficiency with emulsified oily water mixtures.

[5] http://www.ultraspin.com.au/Tutorial%202.htm, accessed 25/7/2003.

[6] Spinifex SP2000 separator (one pass and with recycle) vs Typical High Quality Plate Pack (7 mm plate spacing) vs Typical Budget Plate Pack (12 mm) vs Typical simple gravity settling tank

3. Sampling Methodology

3.1 General

During the period 26 April – 11 June 2003, GHD visited three meat processing sites to assess the performance of operating hydrocyclones for the removal of fat from meat processing wastewater streams. The personnel involved were:

- Chris Hertle
  Principal Process Engineer, Water and Wastewater Treatment
- Jeff Foley
  Process Engineer, Water and Wastewater Treatment

Wastewater samples were collected from the sources shown in Table 1 below.

Table 1 Hydrocyclone Sampling Locations

Stream Sampled	Processing Plant No.1 over 2 days	Processing Plant No.2 over 2 days	Processing Plant No.3 over 2 days
Hydrocyclone Feed	✓ 6 samples	✓ 8 samples	✓ 8 samples
Centrate stream from Hydrocyclone	✓ 6 samples	✓ 8 samples	✓ 8 samples
Solids-rich stream from Hydrocyclone	✓ 5 samples		
Fat-rich stream from Hydrocyclone	✓ 7 samples	✓ 8 samples	✓ 8 samples

Process Flow Diagrams (PFDs) illustrating the inspected installations and the above sampling locations are shown in section 4.1.

3.2 Sampling Equipment

The following equipment was used to collect the wastewater samples:

- Plastic bucket for collecting composite sample;
- Plastic trowel for mixing;
- Plastic, graduated measuring cylinder for collecting samples and measuring volumes;
- Clean plastic and glass sample containers (as supplied by the laboratory), with screw-on plastic lids. Glass sample containers were stored in bubble wrap to prevent breakages; and
- High impact plastic coolers (esky) with ice bricks (for transport to the laboratory).

3.3 Sampling Method

The following sampling methodology was used for each sample collected:

1. Collect large sample of wastewater stream using plastic sampling bucket. Where possible, samples were collected using sampling points fitted on the hydrocyclones. The sampling locations are shown on the PFDs in section 4.1.

2. Mix the collected wastewater sample using the plastic trowel.

3. Fill the required sample containers to the brim and secure the plastic lid.

4. Mark each sample container with the following information:

5. Sampling location;

6. Sample number; and

7. Date and time of sampling (noted on GHD record sheet).

8. Wrap glass sample container in bubble wrap and store in cooler.

9. Measure pH and temperature of composite sample in plastic bucket.

Between each sample, the collection equipment was washed with hot water to minimise contamination. Before the collection of each sample, the collection equipment was rinsed in the stream to be sampled.

Upon completion of site inspections, the wastewater samples were couriered to the Amdel/Gribbles Laboratory in Notting Hill, Victoria. Amdel/Gribbles is NATA-registered for all analyses undertaken in this study.

All sample containers were accompanied by a GHD Chain of Custody Record. These records have been retained in the GHD project file for QA purposes. Amdel/Gribbles also retained a replicate of the Chain of Custody Record for their files.

3.4 Analyses

Outlined in Table 2 are the analyses undertaken by Amdel/Gribbles[7] on the collected samples.

Table 2 Wastewater Analyses

Analyses	COD	Soluble COD	TSS	VSS	O&G	Total Nitrogen	Soluble TN	Total Phosphorus	Soluble TP	Volatile Fatty Acids
Method Description	APHA 5520 D	APHA 5520 D	APHA 2540 C,D	APHA 2540 E Ignited at 550°C	APHA 5520 B	APHA 4500 Norg BCD APHA 4500N C	APHA 4500 Norg BCD APHA 4500N C	ICP-AES [8]	ICP-AES	GC [9]
Plant No.1										
Hydrocyclone Feed	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Centrate Stream	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Solids-rich Stream	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Fat-rich Stream			✓		✓					✓

[7] NATA Accreditation No. 1645 (chemical testing), NATA Accreditation No. 14278 (biological testing) [7] TN – Total Nitrogen

[8] ICP-AES – Inductively Coupled Plasma-Atomic Absorption Spectrometry

[9] Gas Chromatography

Analyses	COD	Soluble COD	TSS	VSS	O&G	Total Nitrogen	Soluble TN	Total Phosphorus	Soluble TP	Volatile Fatty Acids
Plant No.2										
Hydrocyclone Feed	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Centrate Stream	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Fat-rich Stream			✓		✓					✓ **& FFA**
Plant No.3										
Hydrocyclone Feed	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Centrate Stream	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Fat-rich Stream			✓		✓					✓ **& FFA**

GHD also conducted on-site, immediate analyses of temperature and pH on most samples. These analyses were made using a hand-held pH-mV-temperature meter (WP-80, TPS Pty Limited), which was two-point calibrated using standard pH solutions before each site visit.

Free Fatty Acid tests were also conducted on fatty samples from the hydrocyclones at Plant Nos. 2 and 3.

GHD makes the following comments about these analytical methods:

- COD – Method reference: APHA 5520 D – Closed Reflux Colorimetric Method.
  This method is acceptable, and in GHD's experience gives reliable results. It also compares well with the older Open Reflux Method.
- TSS – Method reference: APHA 2540 C, D – Standard Gravimetric Methods.
  This method is acceptable, and in GHD's experience gives reliable results. It can be susceptible to inaccuracies at low SS concentrations. However, in this application, no significant errors are expected.
- VSS – Method reference: APHA 2540 E – 550°C Ignition.
  This method is acceptable, and in GHD's experience gives reliable results. It can be susceptible to errors if blank filter papers have not been correctly prepared, or insufficient duplicate samples are analysed (as described in the procedure). This is mainly a concern at low SS concentrations, and hence in this application, no significant errors are expected.
- Oil & Grease – Method reference: APHA 5520 B – Partition-Gravimetric Method, extraction into organic solvent.
  This method is acceptable, and in GHD's experience gives reliable results. It can be susceptible to occasional problems with emulsion layer formation, especially on samples containing significant amounts of soaps (e.g. industrial effluents) and in sludge samples.
- TN – Method references: APHA 4500 Norg B (Macro Kjeldahl), C (Micro Kjeldahl), D (Automated),
  In GHD's experience, the TKN analyses are very difficult and are susceptible to many problems. However, in a laboratory with high standards of quality control, the reliability of results is acceptable.
- TN – Method references: APHA 4500 N C – Oxidation to Nitrate
  This method oxidizes all of the available N-compounds to nitrate using alkaline persulphate at ~100°C. It is then followed by nitrate analysis by auto-analyser. In GHD's experience, this method is acceptable, provided the auto-analyser is correctly calibrated to account for the background matrix emerging from the digest (i.e. residual sulphate and other ions carried over).
- TP – Inductively Coupled Plasma-Atomic Absorption Spectrometry
  This method is acceptable, and in GHD's experience gives reliable results.
- PO4 – Method reference: APHA 4110 C – Vanadomolybdophosphoric Acid Method.
  This method is acceptable, and in GHD's experience gives reliable results in the range of approx. 1 to 50 mgP/L. For lower concentrations, the "Ascorbic Acid" Method, namely APHA 4500-P E is preferred. In this application, APHA 4110 C is acceptable.
- The VFA analyses by gas chromatograph appear reasonable. The reported spike recovery (on phosphorus) was within acceptable limits for all batches tested (i.e. 100 ± 5%).

4. Processing Plants Characteristics

4.1 Plant Summary

Shown in Table 3 below is a summary of the information collected to characterise the three plants inspected for this project.

Table 3 Meat Processing Plants

Parameter	Plant No.1	Plant No.2	Plant No.3
Date of site visit	26 – 28 April, 2003	29 – 30 April, 2003	10 – 11 June, 2003
Type of plant	Slaughter & dressing – 1 No. beef chain, 1 No. small animals chain No By-products Plant	Slaughter & dressing – 1 No. beef chain, 1 No. small animals chain By-products Plant	Slaughter & dressing – 1 No. beef chain, 1 No. small animals chain, 1 No. pigs chain By-products Plant, Pet Food Plant
Operation hours	5:30 am – 3:30 pm (full shift – varies depending on load) 5:30 am – 12:30 pm (during site visit)	7:30 am – 4:30 pm (full shift – varies depending on load)	6:00 am – 4:30 pm (full shift – varies depending on load)
Source of animals	10 – 15% grain-fed cattle	10 – 15% grain-fed cattle	Cattle and small animals mainly grass-fed Pigs have variable/managed diet, includes lots of meat & bone meal
Water consumption *Average*	Approx. 200 kL/d (Approx. 1.92 L/kg HSCW) [10]	Approx. 790 kL/d (Approx. 9.19 L/kg HSCW)	Approx. 775 kL/d (Approx. 6.46 L/kg HSCW)

[10] Very low water consumption due mainly to limited amount of water used for yard wash down. Yards at Meat Processing Plant No.1 are elevated, and do not require daily cleaning.

Parameter	Plant No.1	Plant No.2	Plant No.3
Seasonal Variation	~ 150 – 250 kL/d. No significant seasonal variation	Higher flows in summer/autumn. Lower flows in winter/spring	Depends on market demands. Up to approx. 1300 kL/d when working 2 shifts per day
Wastewater production	Not metered. Assume water usage ≈ wastewater production. Some additional amount for toilets, animal body fluids etc.	Approx. 680 kL/d.	Not metered. Previous study suggested wastewater discharge (at irrigation) approx. 10% less than water consumption (mainly due to evaporation on ponds). WW flow at hydrocyclone approx. equal to water consumption.
Wastewater treatment processes	Rotary drum screen, equalisation tanks, hydrocyclones (O&G and solids), covered anaerobic lagoon, SBR (single lagoon, surface aerator), irrigation winter storage pond, irrigation agriculture or tanker to sewer disposal. (See PFD below)	*Yard wash-down* Rotary drum screen – solids to disposal, liquid to save-all *Red wastewater* Rotary drum screen – solids to disposal, liquid to save-all. Tallow from save-all to heated collection tank, then to farm spreading, via tanker. Effluent from save-all to Council STP (anaerobic lagoon, SBR and 6 No. maturation lagoons). Discharge to river. (See PFD below)	Surge tank and rotary drum screens – solids to disposal, liquids to collection pit. Side-stream treatment by hydrocyclone and electro-coagulation unit. Bulk flow to uncovered anaerobic lagoons (2 No. in parallel), followed by SBR and maturation/sedimentation lagoons. Effluent discharged by irrigation. Run-off collected in interception dams. (See PFD below)

Parameter	**Plant No.1**	**Plant No.2**	**Plant No.3**
Fat recovery systems			
Previously	Rotary drum screen, equalisation/storage tanks, tanker to agricultural irrigation	Rotary drum screen, save-all	Rotary drum screens
Currently	Hydrocyclones and storage tank	Rotary drum screen, save-all and hydrocyclone for side-stream treatment off save-all. Tallow from hydrocyclone to by-products plant, via skip.	Rotary drum screen, hydrocyclone for side-stream treatment, for feed to electro-coagulation unit. Tallow from hydrocyclone and EC unit pumped directly to by-products plant.
Hydrocyclone details			
Application	Total wastewater stream (inc. paunch and yard washdown). Downstream of 3mm rotary drum screen and equalisation tanks	Side-stream from save-all. Fixed (bellows-type) skimmer on front-end of save-all draws off hydrocyclone feed. Centrate returned to save-all. Tallow collected in heated tank and decanted to skip.	Side-stream from small wastewater collection pit – downstream of rotary drum screens. Tallow collected in unheated tank and pumped to By-products Plant. Centrate stored in Tank for feed to EC Unit.
Supplier	Spinifex Australia (Contact: Kevin O'Brien)	Design by Greeneng Pty Ltd – Unit supplied by Spinifex Australia	Design by Greeneng Pty Ltd – Unit supplied by Spinifex Australia
Model	16 × M28 de-oiling hydrocyclones 16 × U2 de-sanding hydrocyclones	SP10000 – 3 × de-oiling hydrocyclones	SP10000 – 3 × de-oiling hydrocyclones

Parameter	Plant No.1	Plant No.2	Plant No.3
Installation cost	Unknown	Unknown	Approx. $26,000 for skid-mounted system (inc. pump, screen, hydrocyclone). Does not include installation costs.
Installation date	June 2001	Early 2002. Operation suspended in November 2002.	April 2003
Design conditions	30 m^3/hr treated effluent discharge, plus 3.6 m^3/hr fat, plus 3.3 m^3/hr solids, plus 21.4 m^3/hr recycle Hydrocyclones sized for 60 m^3/hr, 450 – 460 kPa feed pressure	10 m^3/hr feed, approx. 490 kPa feed pressure	10 m^3/hr feed, approx. 490 kPa feed pressure
Actual operating conditions	As above, but hydrocyclones drilled out to increase outlet diameters (from 3mm to 4-5mm) to reduce blockages	As above. No changes to hydrocyclone since installation.	As above. No changes to hydrocyclone since installation.
O&G load	No historical data. See sampling program results.	No historical data. See sampling program results.	No historical data. See sampling program results.
Operation hours	Approx. 6:30 am – 3:30 pm (depending on plant operating hours)	Operation currently suspended. Previously operated during normal shift hours.	Approx. 6:30 am – 4:30 pm (depending on plant operating hours). EC unit can run 24 hr/d

Parameter	**Plant No.1**	**Plant No.2**	**Plant No.3**
Power requirement	Bornemann EH1900 15 kW (1460 rpm, direct drive) helical rotor feed pump	Mono CB052AC1J8/G668 3 kW (1400 rpm direct drive) helical rotor feed pump	Mono CB052AC1J8/G138 3 kW (1400 rpm direct drive) helical rotor feed pump
Chemical requirements	Nil	Nil	Nil
O&M requirements	Used to have to clean screen (downstream of pump) once per day to stop blockages by hair/wool. Screen has since been removed. Manually backflush hydrocyclones once per day. Remove hydrocyclone caps once per week to remove hair/wool etc. Approx. 50% of hydrocyclones block after 1 week. Remove fat discharge flexible hoses once per week for cleaning.	Occasional manual operation of rotary brush screen on inlet to hydrocyclone. No major O&M problems reported with hydrocyclone. Major problem with solidification of tallow in storage tank and difficulty in decanting from this vessel. Requires considerable operator attention to operate. This was main reason for suspending operation.	Manual operation of rotary brush screen, with manual valve flushing (~4 times per day). Mainly due to blockages from pig hair. Complete backflush of hydrocyclones (with flexible hose connection) at the end of each day's operations. Occasional (i.e. monthly) disassembly of unit for physical cleaning of hydrocyclone.
Value/quality of recovered fat	No historical data. See sampling program results. Fat manually recovered (by shovel) from top of fat storage silo twice per week. Approx. 1.5 – 2 m^3 per week. Trucked to external by-products plant.	Tallow recovered from save-all is combined with paunch and offal material and removed by tanker (6 $\times$ 10 kL per day) for agricultural fertiliser. Tallow recovered by hydrocyclones of higher quality. Sent directly to by-products plant.	Tallow recovered from hydrocyclone is pumped directly to By-products Plant.

Parameter	**Plant No.1**	**Plant No.2**	**Plant No.3**
Effect of downstream processes	Better performance of anaerobic lagoon and SBR. Reduced solids production in lagoons. Reduced maintenance of treatment lagoons.	Council STP Operator suggested that tallow levels in SBR have increased since operation of hydrocyclone was suspended. Visual inspection of STP confirmed significant accumulation of tallow on SBR. Operator uses floating surface aerators to break up tallow. Leads to increased power costs.	No reported effects on downstream wastewater treatment processes, or By-products Plant processes.
Other comments		Hydrocyclone flushed (tallow has solidified in lines) and re-started for GHD site inspection. No significant problems reported on start-up.	Hydrocyclone mainly used as a pre-treatment unit for the electro-coagulation unit.

Process flow diagrams (PFDs) of each of the inspected facilities are attached below. These illustrate the application of the hydrocyclone in each plant, the design flowrates and the sampling points used in this study.

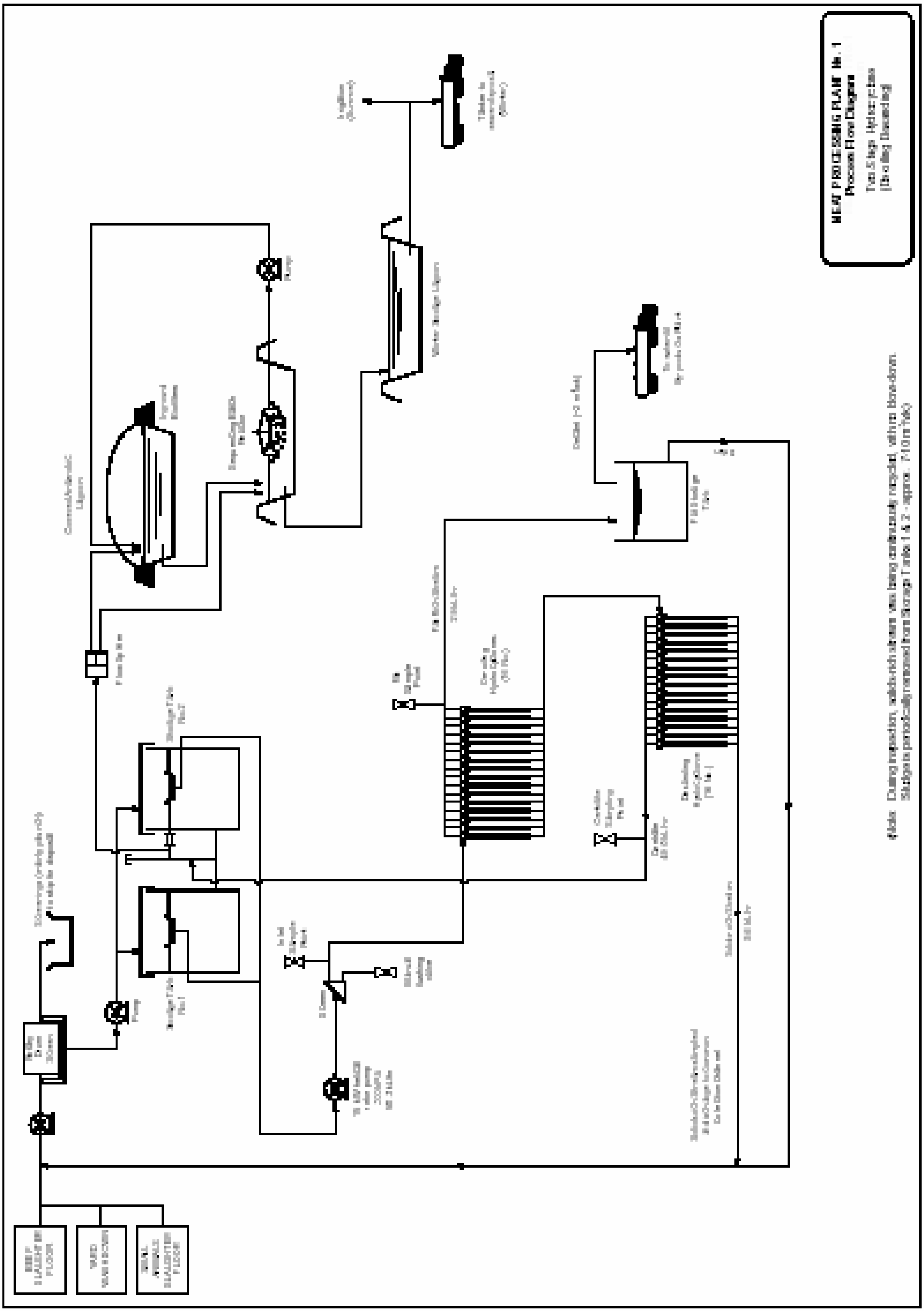

Figure 3 Plant No.1 Process Flow Diagram

Figure 4 Meat Processing Plant No.1 – Hydrocyclone Installation

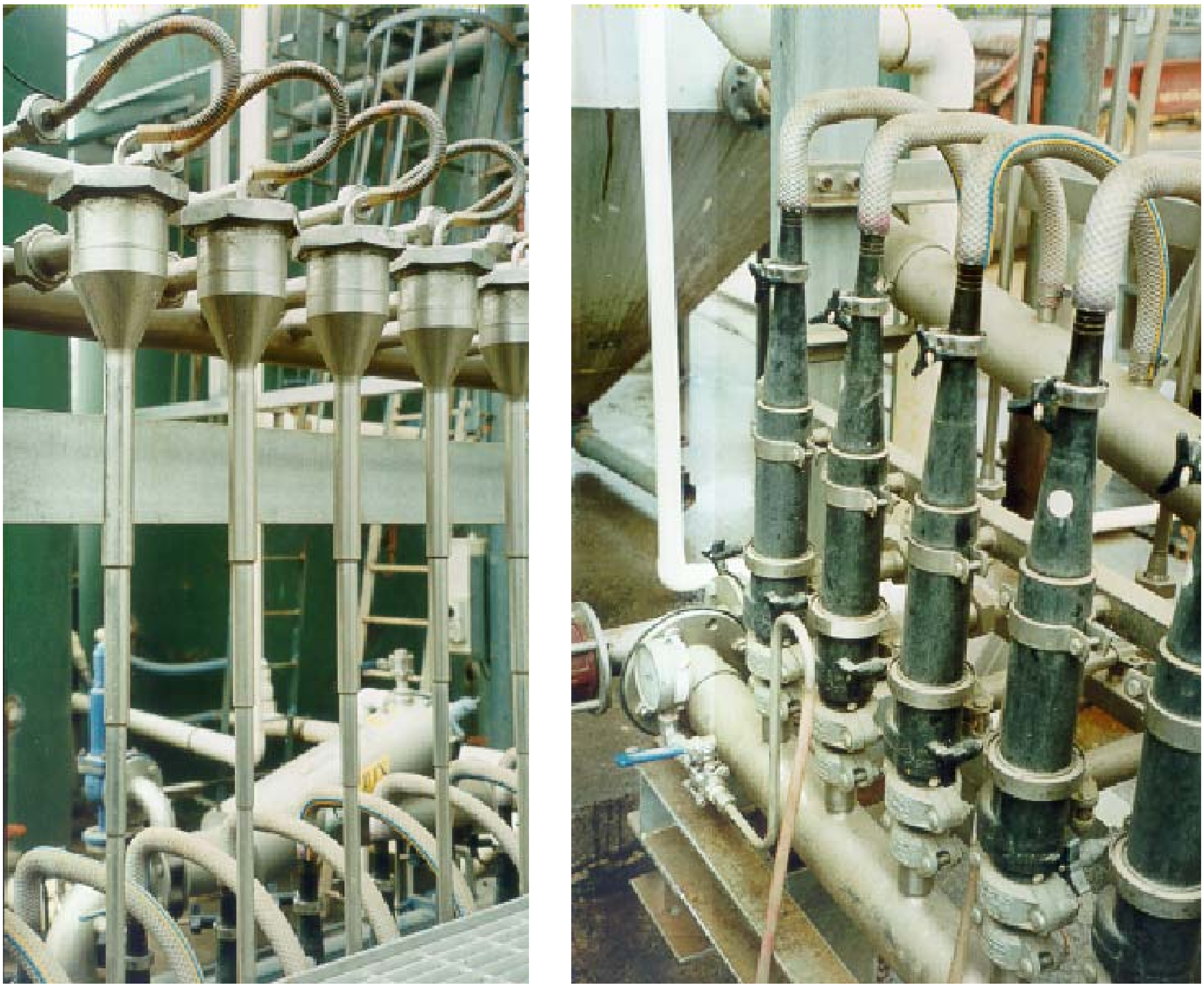

Figure 5 Meat Processing Plant No.1 – De-oiling and De-sanding Hydrocyclones

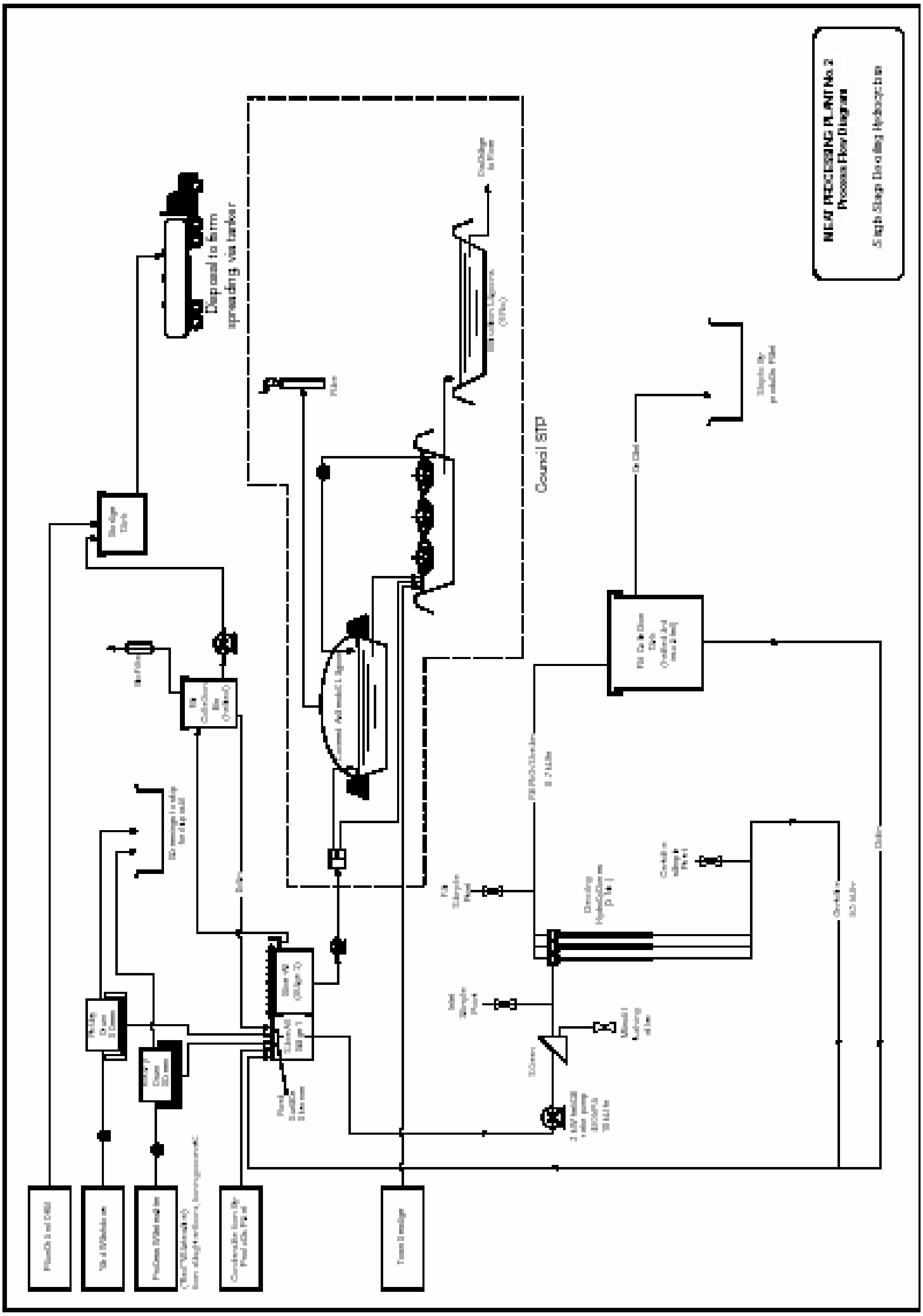

Figure 6 Plant No.2 Process Flow Diagram

Figure 7 Meat Processing Plant No.2 – Hydrocyclone Installation

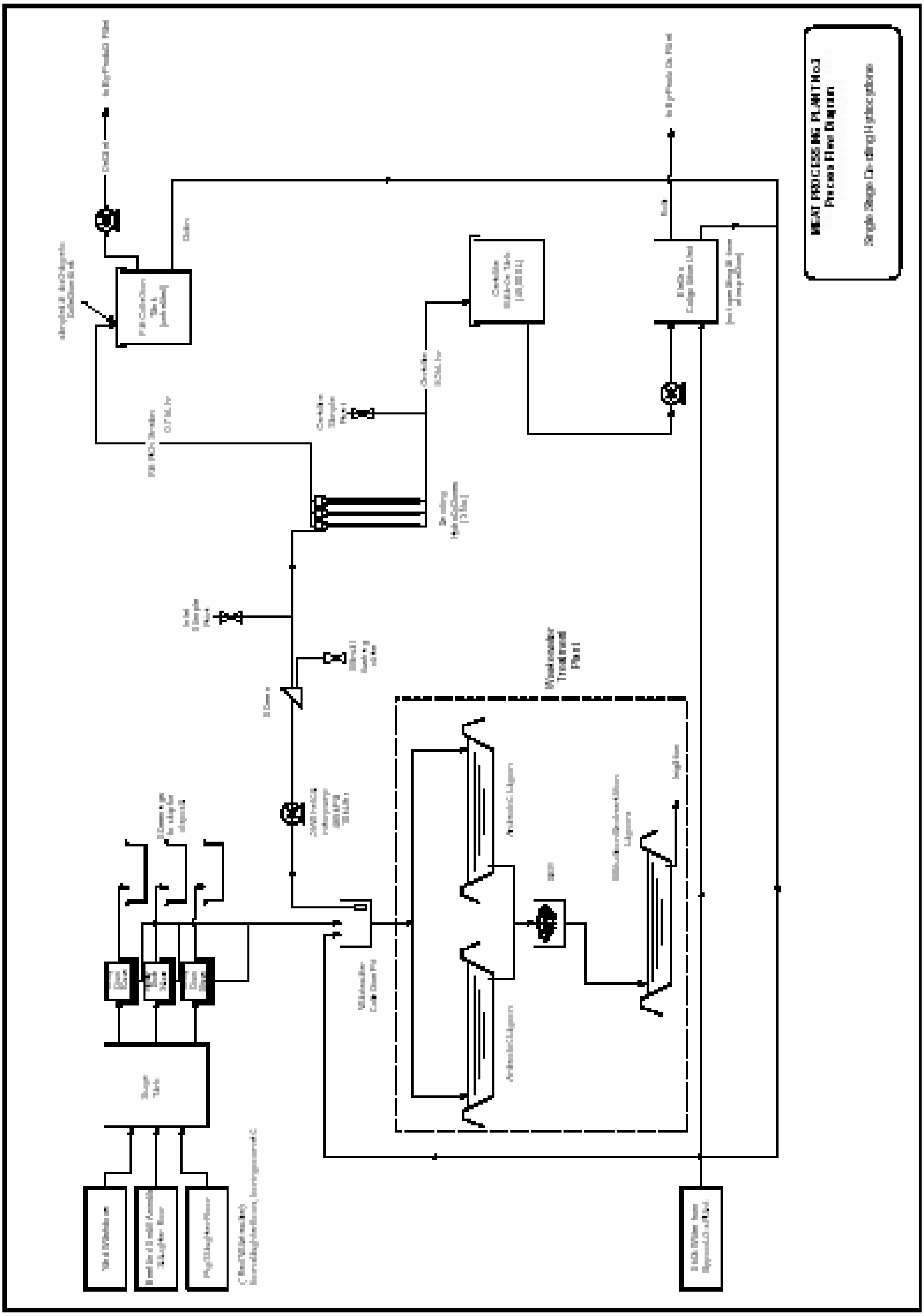

Figure 8 Plant No.3 Process Flow Diagram

Figure 9 Sampling at Plant No.3 Hydrocyclone Installation

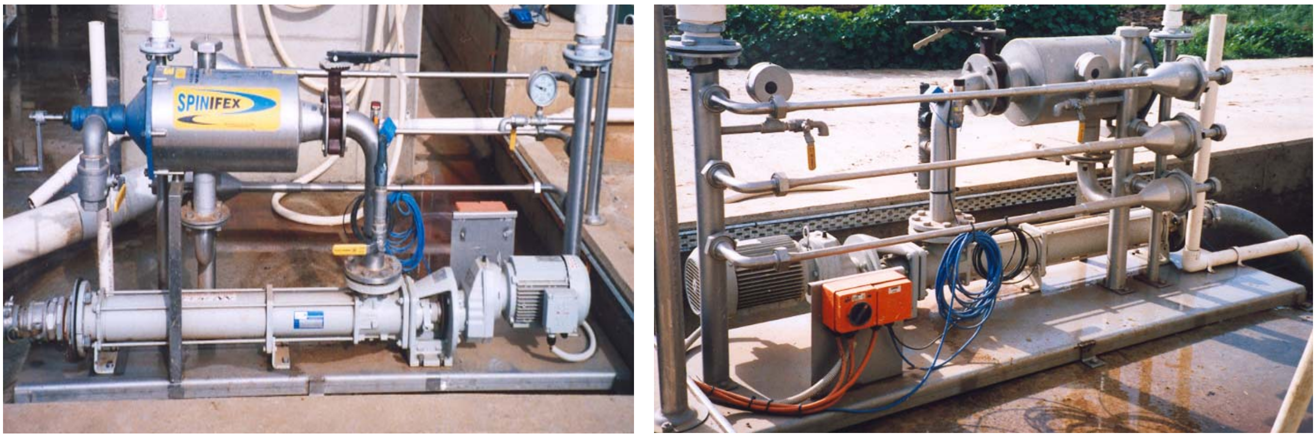

Figure 10 Meat Processing Plant No.3 – Hydrocyclone Installation

4.2 Raw Wastewater Quality

The wastewater quality at meat processing plants can vary widely, due to differences in such things as yard arrangements, type of animal slaughtered, size of operation, treatment equipment and water reduction measures. Shown in Table 4 below are the results of the sampling GHD undertook on the hydrocyclone feed wastewater. It can be seen from the values presented in this table that the strength of raw wastewater varied considerably, due to natural fluctuations. To provide an indication of this variability, the 10th, 50th and 90th percentile results are shown in the table below.

The results for Plant No.2 were split over two days because of significant differences noticed in the operation of the save-all on these two days. On the first day, the save-all was covered in a thick layer of oil and grease scum. However, on the second day this had thinned considerably. This can be seen in the significant difference between the O&G concentrations for the Plant No.2 wastewater over the two days.

Table 4 Raw Wastewater Quality

Parameter	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3		
	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile
COD (mg/L)	2150	2700	3550	2930	3800	4760	3190	3800	4690	2630	3500	4420
Sol. COD (mg/L)	1050	1300	1550	800	900	990	770	1000	1350	1270	1700	2100
SCOD / COD	0.49	0.48	0.44	0.27	0.24	0.21	0.24	0.26	0.29	0.48	0.49	0.48
TSS (mg/L)	685	980	1200	1590	2200	3050	1057	1930	2780	798	1280	1860
VSS (mg/L)	595	850	1045	1530	2100	2910	1057	1880	2680	713	1140	1660
VSS / TSS	0.87	0.87	0.87	0.96	0.96	0.95	1.00	0.97	0.96	0.89	0.89	0.89
O&G (mg/L)	104	190	330	2200	3400	4280	609	1340	2430	118	200	306
TN (mg/L)	150	180	210	160	180	215	140	190	257	188	230	283
Sol. TN (mg/L)	125	150	175	110	120	141	97	120	155	144	170	199
STN / TN	0.83	0.83	0.83	0.69	0.67	0.66	0.69	0.63	0.60	0.77	0.74	0.70
TP (mg/L)	20	25	31	13	15	16	9	13	16	16	27	39

Parameter	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3		
	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile
Sol. TP (mg/L)	20	25	31	10	13	15	7	11	15	16	27	39
STP / TP	1.00	1.00	1.00	0.77	0.87	0.94	0.78	0.85	0.94	1.00	1.00	1.00
PH	7.40	7.52	7.69	7.48	7.71	8.00	7.47	7.60	7.69	7.80	8.00	8.16
Temp. (°C)	17.7	18.9	20.0	36.2	36.8	37.5	35.4	36.2	37.1	28.4	28.9	29.4
Water usage	27/5/03 – 163 kL 28/5/03 – 202 kL			29/5/03 – 1,177 kL			30/5/03 – 1,081 kL			10/6/03 – 890 kL 11/6/03 – 895 kL		
Animals slaughtered	27/5/03: 212 beef, 549 calves, 366 lambs 28/5/03: 210 beef, 204 calves, 108 lambs			29/5/03: 349 beef, 1271 small animals (lambs, sheep, calves)			30/5/03: 359 beef, 1266 small animals (lambs, sheep, calves)			10/6/03: 1350 pigs, 1691 sheep & lambs, 103 beef 11/6/03: 1250 pigs, 2000 sheep & lambs, 120 beef		
Other comments	During GHD's site visit, the plant was operating at low throughput. There was no washing of yards conducted during site visit days. The ambient temperature was very cold (approx. 8 - 12°C).			On Day 1, the save-all was noted to have a very thick layer of O&G/foam on the surface, particularly around the skimmer inlet to the hydrocyclone.			On Day 2, the save-all did not have a thick layer of O&G/foam on the surface. This is reflected in the significantly lower O&G results above.			No unusual operating circumstances noted.		

Other points to note are:

- The kills at Plant No.1 on the days of GHD's site visits were significantly lower than normal, especially for small animals. However, the water consumption was average (i.e. approx. 200 kL/d).
- The kill at Plant No.1 on the second day of GHD's site visit was significantly lower than the kill on the first day, yet the water consumption was higher.
- The kills at Plant No.2 on the days of GHD's site visits were slightly higher than normal. Water consumption was significantly higher than average (i.e. approx. 1100 kL/d vs 790 kL/d).
- The kills at Plant No.3 on the days of GHD's site visits were slightly higher than normal, due to a shorter working week (i.e. public holiday on 9 June 2003). Water consumption was average.
- In general, the strength of hydrocyclone feed at Plant No.1 is weaker than the other two plants. This is because the hydrocyclone feed includes a significant Centrate recycle, which acts to dilute the incoming raw wastewater. Also, the low kill rate but still average water consumption would act to dilute the raw wastewater.
- The O&G concentration in the hydrocyclone feed at Plant No.2 was significantly higher than the other two plants. It was also higher than the historical wastewater O&G concentration suggested by records collected from the plant (i.e. May 2002 – May 2003: average wastewater O&G concentration = 810 mg/L, 90 percentile concentration = 1150 mg/L). This could possibly be due to such factors as:
  - The hydrocyclone feed is drawn from the top of the save-all by a surface skimmer;
  - The kill rates during GHD's inspection were slightly higher than normal; and
  - The proportion of beef processed at this plant is higher than the other plants inspected.
- The hydrocyclone feed at Plant No.1 was also drawn from storage tanks by surface skimmers, however, this feed was then diluted with recycled Centrate;
- The fractions of soluble COD (over total COD), soluble nitrogen (over total nitrogen) and soluble phosphorus (over total phosphorus) at Plant No.2 were lower than the other plants. This is possibly because the hydrocyclone feed at Plant No.2 is drawn off a save-all with a surface skimmer, leading to a higher than normal fraction of buoyant particulate material, and hence a lower soluble fraction.
- The fraction of soluble phosphorus, in comparison to total phosphorus, is very high (approaching 100%) at all three plants;
- pH was quite constant and in the range of 7.5 – 8.0 across al three plants. This is considered typical for meat processing wastewater.
- Wastewater temperature was very steady at all three plants throughout all the trials conducted. The wastewater temperature at Plant No.1 was markedly lower than the other two plants. This is because the wastewater at Plant No.1 is stored in an un-insulated tank prior to processing in the hydrocyclone. The ambient temperature at Plant No.1 was also much lower.

These results, together with the rated capacity of the feed pumps to the hydrocyclone units provided the basis for the mass balance calculations reported in the following section.

5. Analytical Results and Discussion

5.1 Centrate Quality

5.1.1 Analytical Results

Each of the three meat processing plants visited by GHD for this study had very limited historical data to assist in quantifying the performance of their wastewater pre-treatment facilities. Therefore the assessment of the hydrocyclones' performance is based almost entirely upon the samples collected during GHD's site visits.

Table 5 below summarises the analytical results from the hydrocyclone centrate samples collected at the three plants. As with the raw wastewater sampling results, the 10^{th}, 50^{th} and 90^{th} percentiles have been presented to provide an indication of the variability in wastewater strength. Again, the results for Plant No.2 are split over two days because of significant differences noticed in the operation of the Save-all on these two days.

Detailed calculations, including the individual sample results, are attached in Appendix C.

Table 5 Centrate Quality

Parameter	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3		
	10^{th} %ile	50^{th} %ile	90^{th} %ile	10^{th} %ile	50^{th} %ile	90^{th} %ile	10^{th} %ile	50^{th} %ile	90^{th} %ile	10^{th} %ile	50^{th} %ile	90^{th} %ile
COD (mg/L)	1950	2700	3750	3260	3600	3920	2830	3500	4440	2250	3100	3890
Sol. COD (mg/L)	990	1300	1650	780	900	1080	1020	1200	1380	1340	1600	1830
SCOD/COD	0.51	0.48	0.44	0.24	0.25	0.28	0.36	0.34	0.31	0.60	0.52	0.47
TSS (mg/L)	545	730	965	2330	3000	4110	721	1020	1420	584	1120	1580
VSS (mg/L)	485	670	935	2090	2830	3940	642	940	1335	553	1000	1390
VSS/TSS	0.89	0.92	0.97	0.90	0.94	0.96	0.89	0.92	0.94	0.93	0.89	0.88
O&G (mg/L)	63	90	125	9930	11730	14500	115	200	313	91	180	298
TN (mg/L)	145	190	225	169	180	207	166	200	253	180	220	253
Sol. TN (mg/L)	125	160	195	103	120	127	123	140	158	140	170	193

Parameter	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3		
	10^{th} %ile	50^{th} %ile	90^{th} %ile	10^{th} %ile	50^{th} %ile	90^{th} %ile	10^{th} %ile	50^{th} %ile	90^{th} %ile	10^{th} %ile	50^{th} %ile	90^{th} %ile
STN/TN	0.86	0.84	0.87	0.61	0.67	0.61	0.74	0.70	0.62	0.78	0.77	0.76
TP (mg/L)	20	26	33	14	17	19	11	14	16	19	26	33
Sol. TP (mg/L)	20	26	33	12	14	16	9	12	15	19	26	33
STP/TP	1.00	1.00	1.00	0.86	0.82	0.84	0.82	0.86	0.94	1.00	1.00	1.00
pH	7.21	7.46	7.66	7.50	7.71	7.89	7.49	7.67	7.86	7.69	7.91	8.19
Temp. (°C)	18.4	19.1	20.1	35.6	35.9	36.3	36.1	36.7	37.4	28.0	28.7	29.1
Comments	Results were quite variable. Standard deviations for many parameters greater than 20% of 50^{th} percentile.			Results were quite variable. Standard deviations for many parameters greater than 20% of 50^{th} percentile. In particular, standard deviations for TSS/VSS greater than 40% of 50^{th} percentile.			Results were quite variable. Standard deviations for many parameters greater than 20% of 50^{th} percentile. In particular, standard deviations for TSS/VSS and O&G greater than 40% of 50^{th} percentile.			Results were quite variable. Standard deviations for many parameters greater than 20% of 50^{th} percentile. In particular, standard deviations for TSS/VSS and O&G greater than 40% of 50^{th} percentile.		

Given the high variability of the analytical results on the raw wastewater and hydrocyclone centrate streams, it is very difficult to accurately quantify the treatment performance of the hydrocyclones. To make a reasonable estimation of the hydrocyclones' effectiveness, two methods of analysis were undertaken:

1. The first method examined the removal percentage of each parameter on corresponding samples – e.g. the mass flow rate (kg/s) of COD in the raw wastewater sample No.1 at Plant No.1 versus the mass flow rate (kg/s) of COD in the centrate sample No.1 at Plant No.1.

2. The second method examined the removal percentage of each parameter, based on the whole data set collected for each Plant. In the case of Plant No.2, results from individual days were handled separately.

In both instances, the removal percentages were calculated based on **mass flowrates**, according to the following general formula:

$$\%\text{Removal} = 100 \times \frac{(\text{Raw.Wastewater.Flow} \times \text{Raw.Wastewater.Concentration}) - (\text{Treated.Wastewater.Flow} \times \text{Treated.Wastewater.Concentration})}{(\text{Raw.Wastewater.Flow} \times \text{Raw.Wastewater.Concentration})}$$

Shown below in Table 6 are the estimated removal percentages for each analysed parameter, as calculated by both of the methods described above. This table presents a range of removal percentages, from the estimated 10th percentile to the estimated 90th percentile to provide an indication of the variability of the wastewater streams' concentrations and the hydrocyclones' performance.

In many instances, particularly on the first day of testing at Plant No.2, the variability of the results was such the concentrations in the centrate stream were higher than the raw wastewater stream, leading to negative removal percentages. For the sake of clarity, these results have been omitted from the table below. A full set of detailed calculations, including negative results, is attached in Appendix C.

Table 6 Contaminant Removal (%) in Centrate

Parameter	Analysis Method	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3			Overall Approximate % Removal
		10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	
COD	(1)	2	16	29	-	9	27	7	14	19	-	16	36	10 – 30%
	(2)	13	31	51	-	19	33	13	25	39	18	32	47	
Soluble COD	(1)	2	13	23	-	5	25	-	-	4	-	10	33	5 – 25%
	(2)	11	25	40	8	15	26	-	5	23	9	22	35	
TSS	(1)	23	35	51	-	-	-	30	45	65	-	15	54	15 – 60%
	(2)	32	45	60	-	-	18	46	61	75	21	42	63	
VSS	(1)	16	31	50	-	-	-	33	47	68	-	14	55	15 – 60%
	(2)	27	42	58	-	-	23	53	64	77	18	39	61	
O&G	(1)	28	52	68	-	-	-	71	79	91	-	11	71	40 –90%
	(2)	51	67	80	-	-	-	83	89	94	12	40	66	
Total N	(1)	0	13	25	-	2	16	-	-	8	-	11	25	10 – 25%
	(2)	10	22	37	-	9	20	-	13	33	11	22	35	

Parameter	Analysis Method	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3			Overall Approximate % Removal
		10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	10th%ile	50th%ile	90th%ile	
Soluble Total N	(1)	0	13	25	-	2	16	-	-	8	-	11	25	10 – 20%
	(2)	9	21	35	6	16	25	-	5	20	8	17	28	
Total P	(1)	9	12	17	-	-	1	-	-	23	-	4	24	10 – 25%
	(2)	10	23	38	-	2	13	3	17	34	11	26	45	
Soluble Total P	(1)	10	13	17	-	-	9	-	-	24	-	5	24	10 – 25%
	(2)	11	23	39	-	5	20	-	18	39	12	28	46	

Note: Only positive results shown

5.1.2 Discussion of Analytical Results

COD and Soluble COD Removal

The relatively low percentage of COD removal (10 – 30%) reported by these trials suggests that there is very little biological activity in the hydrocyclone contributing to the treatment performance. This is not surprising, given the very short residence time in the hydrocyclone (i.e. in the order of seconds). At this short residence time, there would be negligible biological activity. Therefore, the removal of COD and soluble COD from the wastewater stream is due almost entirely to physical separation.

The removal of soluble COD is due to part of the liquid phase exiting the hydrocyclone in the fat-rich stream. The slightly higher removal percentage for total COD suggests that some buoyant particulate COD is also removed in the fat-rich stream.

There does not appear to be any significant difference between the results from the three different plants.

The results from analysis method (1) (i.e. – comparison of individual samples) suggest lower removal percentages than those determined by analysis method (2) (i.e. comparison of whole stream data sets). This suggests that the statistical rationalisation of a complete data set may artificially increase the resultant contaminant removal percentages.

TSS and VSS Removal

The overall removal percentages for TSS and VSS are in line with the expectation for a non-chemical dosing removal technology. A high percentage of the solids present in meat processing wastewater are near-buoyant (i.e. O&G particles etc.) and hence a relatively high degree of separation from a de-oiling hydrocyclone can be expected. This is reflected in the above results, with approximately 15 – 60% TSS/VSS removal.

Surprisingly, the treatment system at Meat Processing Plant No.1, which includes a solids separation stage, did not report a significantly higher percentage of solids removal than the other plants investigated. This is further corroborated by the results presented in Table 8 below.

There is no significant difference between TSS and VSS removal for the hydrocyclone. This is not surprising, given the very short residence time in the hydrocyclone. Consequently, there is no significant opportunity for the aerobic or anaerobic destruction of the volatile solids. Therefore, the removal of TSS and VSS in hydrocyclones is due entirely to simple density-based separation. There is negligible biological activity contributing to the treatment performance.

There does not appear to be any significant difference between the results from the three different plants.

Oil & Grease Removal

The results from Plant No.1 show clear and consistent O&G removal in the order of 50 – 70%, under both analytical methods.

The results from day 1 at Plant No.2 are completely discarded. The O&G concentrations recorded in both the raw wastewater and centrate streams were extremely high and variable. The resultant removal percentages were less than 0%. The cause of these anomalous results is difficult to pinpoint. However, as discussed earlier, the Save-all at Plant No.2 was observed to have a very thick layer of scum around the skimmer suction point on day 1. Kill rates were slightly higher than normal and water usage was also higher than normal, but neither of these factors is considered to be a significant contributor. The hydrocyclone unit at Plant No.2 had been out of operation for up to 6 months before the day of GHD's site visit. This long period of inactivity may have left significant deposits of tallow in the unit which were captured during the first day of GHD's sampling program.

The results from day 2 at Plant No.2 are very impressive, with consistent O&G removal in the order of 80 – 90%. This suggest that the problems that afflicted the unit on day 1 were absent on day 2. There were no changes in GHD's sampling methodology over the two days, so it can be concluded that the variability in results on day 1 was due to inherent operational problems.

The results from Plant No.3 were reasonably consistent, with O&G removal of approximately 40 – 70%. There were some exceptions to this, with the last three samples collected reporting negative removal percentages. Again, this highlights the variability of the wastewater streams and the difficulty in quantifying the systems' performance.

In general, it is remarked that the hydrocyclone achieves a reasonable level of O&G removal for a system that relies purely on physical forces, with no chemical additives. Furthermore, it is able to achieve this high degree of separation within a very small footprint, in comparison to a similar chemical-free physical separation process, such as a Save-all. This short residence time has additional benefits in terms of quality of fat recovered, as is discussed below in section 5.3.2.

TN and Soluble TN Removal

The relatively low percentage of nitrogen removal (10 – 25%) reported by these trials again suggests that there is very little biological activity in the hydrocyclone contributing to the treatment performance. Certainly there is insufficient time for any nitrification/denitrification activity, and no opportunity for ammonia volatilisation. Therefore, the removal of nitrogen and soluble nitrogen from the wastewater stream is due almost entirely to physical separation.

As with soluble COD, the removal of soluble nitrogen is due to part of the liquid phase exiting the hydrocyclone in the fat-rich stream. The slightly higher removal percentage for total nitrogen suggests that some buoyant particulate organic material is also removed in the fat-rich stream.

There does not appear to be any significant difference between the results from the three different plants.

TP and Soluble TP Removal

The relatively low percentage of phosphorus removal (10 – 25%) reported by these trials confirms that there is very little biological activity in the hydrocyclone contributing to the treatment performance. Treatment is primarily by physical separation.

There does not appear to be any significant difference between the results from the three different plants for phosphorus removal.

5.2 Solids-rich Wastewater Quality

5.2.1 Analytical Results

Table 7 below summarises the analytical results from the solids-rich wastewater samples collected at the Meat Processing Plant No.1 only. This solids-rich stream is only generated by a 2-stage hydrocyclone unit (i.e. de-oiling hydrocyclone, followed by de-sanding hydrocyclone). This type of unit was only installed at Plant No.1 (refer to the process flow diagram in Figure 3 above).

Detailed calculations, including the individual sample results, are attached in Appendix C.

Table 7 Solids-rich Wastewater Quality

Parameter	**Plant No.1**		
	10th %ile	**50th %ile**	**90th %ile**
COD (mg/L)	2210	2900	3500
Soluble COD (mg/L)	1100	1300	1470
SCOD/COD	0.50	0.45	0.42
TSS (mg/L)	732	970	1280
VSS (mg/L)	680	760	876
VSS/TSS	0.93	0.78	0.68
O&G (mg/L)	47	80	102
Total N (mg/L)	159	190	218
Soluble Total N (mg/L)	123	150	167
STN/TN	0.77	0.79	0.77
Total P (mg/L)	21	24	27
Soluble Total P (mg/L)	21	24	27
STP/TP	1.00	1.00	1.00
pH	7.38	7.50	7.66
Temp. (°C)	18.9	19.3	19.8

As with the centrate stream two methods of analysis were undertaken to assess the hydrocyclones' performance:

1. The first method examined the recovery percentage of each parameter on corresponding samples – e.g. the mass flow rate (kg/s) of COD in the raw wastewater sample No.1 at Plant No.1 versus the mass flow rate (kg/s) of COD in the solids-rich wastewater sample No.1 at Plant No.1.

2. The second method examined the removal percentage of each parameter, based on the whole data set collected for the Plant.

In both instances, the removal percentages were calculated based on **mass flowrates**, according to the following general formula:

$$\%\text{Recovery} = 100 \times \frac{\text{Solids} - \text{rich.Wastewater.Flow} \times \text{Solids} - \text{rich.Wastewater.Concentration}}{\text{Raw.Wastewater.Flow} \times \text{Raw.Wastewater.Concentration}}$$

Shown below in Table 8 are the estimated recovery percentages for each analysed parameter, as calculated by both of the methods described above. This table presents a range of recovery percentages, from the estimated 10^{th} percentile to the estimated 90^{th} percentile to provide an indication of the variability of the wastewater streams' concentrations and the hydrocyclones' performance.

A full set of detailed calculations is attached in Appendix C.

Table 8 Contaminant Recovery (%) in Solids-rich Wastewater

Parameter	Analysis Method	Plant No.1		
		10^{th} %ile	50^{th} %ile	90^{th} %ile
COD	(1)	9	11	13
	(2)	7	11	15
Soluble COD	(1)	9	10	11
	(2)	7	10	13
TSS	(1)	9	10	11
	(2)	7	10	14
VSS	(1)	7	10	12
	(2)	7	9	12
O&G	(1)	2	5	9
	(2)	2	5	8
Total N	(1)	9	11	13
	(2)	8	10	13
Soluble Total N	(1)	9	10	11
	(2)	7	10	12
Total P	(1)	10	10	11
	(2)	8	10	12
Soluble Total P	(1)	9	10	12
	(2)	8	10	12

5.2.2 Discussion of Analytical Results

The results shown in Table 8 above indicate that the recovery of solid material from the hydrocyclone installation at Plant No.1 is quite limited. Approximately 10% of the solid material entering in the feed stream is recovered in the solids-rich stream. The fact that all of the parameters (except O&G) indicate an approximate recovery percentage of ~10% confirms earlier indications that the treatment performance of the hydrocyclone is reliant upon physical separation only. There is no biological or chemical activity in the hydrocyclone to enhance treatment performance.

Interestingly, the recovery percentage of O&G is lower than the other parameters. This confirms that the solids-removal hydrocyclone operates as designed, with removal of heavier-than-water particles in preference to the buoyant O&G particles.

5.3 Fat-rich Wastewater Quality

5.3.1 Analytical Results

Table 9 below summarises the analytical results from the hydrocyclone fat-rich samples collected at the three plants. Again, the 10^{th}, 50^{th} and 90^{th} percentiles have been presented to provide an indication of the variability in wastewater strength. The results for Plant No.2 are split over two days because of significant differences noticed in the operation of the Save-all on these two days.

Table 9 Fat-rich Wastewater Quality

Parameter	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3		
	10th %ile	50th %ile	90th %ile	10th %ile	50th %ile	90th %ile	10th %ile	50th %ile	90th %ile	10th %ile	50th %ile	90th %ile
TSS (mg/L)	775	1330	2100	49300	59750	70400	8570	12780	17200	1500	3230	5480
O&G (mg/L)	305	1080	2150	38900	42250	45400	12300	14250	16800	1174	2700	4680
FFA (%) *				-	3.9	-	-	1.8	-	-	0.3	-
VFA (mg/L) *	950	1160	1414	646	800	963	342	520	783	16	310	598
pH	7.30	7.53	7.70	-	-	-	-	-	-	7.95	8.06	8.16
Temp. (°C)	18.2	19.1	20.2	-	-	-	-	-	-	26.9	28.4	29.7
Comments	Results were quite variable. Standard deviations for TSS and O&G were greater than 50% of 50th percentile.			Fat samples were very dirty and viscous (e.g. like a paste). Temperature and pH could not be measured. Sample for FFA analysis was taken directly from the Fat Collection Tank (refer to process flow diagram in Figure 6). Sample for VFA analysis was taken directly from the fat-rich stream outlet of the hydrocyclone.			Fat samples were very dirty and viscous (e.g. like a paste). Temperature and pH could not be measured. Results were quite variable. Standard deviations for TSS and VFA were greater than 40% of 50th percentile. Sample for FFA analysis was taken directly from the fat-rich stream outlet of the hydrocyclone.			Due to delays by laboratory, samples from day 2 were not analysed for VFA – "Insufficient sample to resend fro VFA Testing". Results were quite variable. Standard deviations for TSS, O&G and VFA were greater than 50% of 50th percentile.		

* As oleic acid

Given the high variability of the analytical results on the raw wastewater and the fat-rich streams, it is very difficult to accurately quantify the treatment performance of the hydrocyclones. To make a reasonable estimation of the hydrocyclones' effectiveness, two methods of analysis were undertaken:

1. The first method examined the recovery percentage of each parameter on corresponding samples – e.g. the mass flow rate (kg/s) of O&G in the raw wastewater sample No.1 at Plant No.1 versus the mass flow rate (kg/s) of O&G in the fat-rich wastewater sample No.1 at Plant No.1.

2. The second method examined the recovery percentage of each parameter, based on the whole data set collected for each Plant. In the case of Plant No.2, results from individual days were handled separately.

In both instances, the recovery percentages were calculated based on **mass flowrates**, according to the following general formula:

$$\%Recovery = 100 \times \frac{Fat - rich.Wastewater.Flow \times Fat - rich.Wastewater.Concentration}{Raw.Wastewater.Flow \times Raw.Wastewater.Concentration}$$

Shown below in Table 10 are the estimated recovery percentages for each analysed parameter, as calculated by both of the methods described above. This table presents a range of recovery percentages, from the estimated 10^{th} percentile to the estimated 90^{th} percentile to provide an indication of the variability of the wastewater streams' concentrations and the hydrocyclones' performance.

In many instances, the variability of the results was such that recovery percentages greater than 100% are reported. For the sake of clarity, these results have simply been shown at "> 100" in the table below.

Table 10 Contaminant Recovery (%) in Fat-rich Wastewater

Parameter	Analysis Method	Plant No.1			Plant No.2 – Day 1			Plant No.2 – Day 2			Plant No.3			Overall Approximate % Recovery
		10^{th}%ile	50^{th}%ile	90^{th}%ile	10^{th}%ile	50^{th}%ile	90^{th}%ile	10^{th}%ile	50^{th}%ile	90^{th}%ile	10^{th}%ile	50^{th}%ile	90^{th}%ile	
TSS	(1)	2	6	9	> 100	> 100	> 100	30	59	91	7	21	35	10 – 60%
	(2)	3	7	11	> 100	> 100	> 100	30	56	93	8	21	39	
O&G	(1)	7	26	55	34	84	> 100	56	> 100	> 100	23	> 100	> 100	10 – 90%
	(2)	7	32	69	68	95	> 100	43	> 100	> 100	39	> 100	> 100	

5.3.2 Discussion of Analytical Results

TSS Recovery

The solids recovery percentage in the fat-rich stream is quite varied across the three plants. However, it is clear that a significant percentage of solids are removed by the hydrocyclone in the fat-rich stream. In general, it is noted that the recovery percentage of TSS is similar to the recovery percentage of O&G. Therefore, it could be concluded that solid material recovered by the hydrocyclone is largely the buoyant fatty solids present in the wastewater.

The results from the two analysis methods are quite similar across all three plants.

O&G Recovery

As with TSS, the recovery percentage of O&G in the fat-rich stream varies quite widely across the three plants. However, despite the difficulty of accurately quantifying an exact figure, it is quite clear that the hydrocyclone does achieve a relatively high degree of fat recovery.

It must be noted however that for most of the samples, across all of the parameters tested, the mass balances do not close with any great accuracy (i.e. < ± 20% – refer to section 5.4 below). Therefore, the high O&G recovery percentages reported in this section must be considered in conjunction with the removal percentages discussed in section 5.1.1, when assessing the hydrocyclones' effectiveness.

The results from the two analysis methods are quite similar across all three plants.

Free Fatty Acids / Volatile Fatty Acids

Fats are chemically defined as "triesters of glycerol". Most animal body fats are triglycerides, consisting of glycerol and three fatty acids. When an animal is slaughtered, enzymes (in a warm, moist environment) start hydrolysing the body fat, which releases the fatty acids as free fatty acids (FFA). In beef tallow, the major fatty acids are [11]:

1. Oleic acid (unsaturated) (C_{18}) – 40%
2. Myristic acid (saturated) (C_{14}) – 3%
3. Palmitic (saturated) acid (C_{16}) – 28%
4. Linoleic acid (unsaturated) (C_{18}) – 2%
5. Stearic acid (saturated) (C_{18}) – 24%
6. Lauric acid (saturated) (C_{12}) – 0.2%

In the beef industry, FFA is measured using an industry-standard sodium hydroxide titration test, which reports %FFA (as oleic acid) [12]. This test is basically an indication of how much the fatty material has degraded and is used by Tallow Suppliers as a measure for fixing price – i.e. the lower the %FFA, the higher the price per tonne of tallow [13].

As shown above, most of the FFAs in beef tallow are long-chain molecules (C_{16} and above). In the appropriate environment, these long chain fatty acids can undergo further decomposition to shorter chain fatty acids or volatile fatty acid (i.e. C_7 and below – e.g. valeric acid, caproic acid, butyric acid etc.). These volatile acids are the pungent odours associated with fatty material. GHD conducted VFA tests as part of this study to also provide an indication of how much FFA had been further reduced to the odorous VFA compounds in the hydrocyclone units.

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[11] Hart, H., D. Hart, L. Craine, (1995). *Organic Chemistry: A Short Course*, 9th ed., Houghton Miffin, Boston.

[12] Meat Research Laboratory, CSIRO, (1984). "Measurement of Free Fatty Acid in Tallow", *Meat By-products Processing – Workshop Notes*.

[13] Kassulke, D. (August 2003). *Personal communication.*

For wastewater treatment processes aimed at recovering O&G for further processing in By-products Plants, the key is to minimise retention time so that the accumulation of FFAs and VFAs is also minimised. The enzymes that hydrolyse the body fat are deactivated by high temperature (i.e. > 70°C), so when fatty material is subsequently rendered in a By-products Plant, the resultant tallow should be stable.

This is one of the key advantages of the hydrocyclone. Its very short retention time (in the order of seconds), in comparison to other technologies such as DAF (retention time in the order of minutes) should result in a fat-rich stream with very low %FFA. This conclusion is supported by the %FFA results reported in Table 9 above.

At these low %FFA values, the fat-rich stream can be sent directly to a By-products Plant for rendering to produce a relatively high grade tallow.

Table 9 also shows that a reasonably significant degree (approx. 5 – 10%) of the free fatty acids are further reduced to the odorous VFA compounds (both expressed as oleic acid). These results indicate that even with the very short residence time in the hydrocyclone, the residence time through the entire wastewater treatment system (i.e. collection drains, surge pits, screens, pumps etc.) is sufficient to allow a significant degree of fat hydrolysis and fermentation to produce FFAs and VFAs.

5.4 Summary of Analytical Results

Shown below in Table 11 is a summary of the removal and recovery percentages calculated from the sampling results at the three meat processing plants. These results certainly indicate that the hydrocyclones are capable of achieving a significant degree of contaminant removal and recovery. It should be noted however that for most samples and most measured parameters, the mass balances do not close to any great accuracy (i.e. < ± 20%). This is due to the inherent variability of the analytical results and the difficulty of accurately measuring the various stream flow rates.

However, this study has demonstrated that the hydrocyclone is an effective wastewater treatment process, with particularly good removal rates for suspended solids and O&G.

Table 11 Summary of Analytical Results

Parameter	Removal Percentage in Centrate	Recovery Percentage in Fat-rich Stream	Recovery Percentage in Solids-rich Stream
COD	10 – 30%	-	Approx. 10%
Soluble COD	5 – 25%	-	Approx. 10%
TSS	15 – 60%	10 – 60%	Approx. 10%
VSS	15 – 60%	-	Approx. 10%
O&G	40 –90%	10 – 90%	Approx. 5%
Total N	10 – 25%	-	Approx. 10%
Soluble Total N	10 – 20%	-	Approx. 10%
Total P	10 – 25%	-	Approx. 10%
Soluble Total P	10 – 25%	-	Approx. 10%

The sampling program results also confirm that the hydrocyclones operate by means of physical separation only. The very short residence time in the unit (in the order of seconds) does not allow for any biological activity and none of the units inspected employed chemical dosing. However, it would be possible, with sufficient mixing time upstream, to use chemical additives to improve the treatment performance of the hydrocyclone.

The main supplier of hydrocyclones in Australia is Spinifex Australia Pty Limited (now known as Ultraspin Pty Limited). As part of their technical literature on hydrocyclones, they report high treatment efficiencies, similar to those concluded by this study. Spinifex/Ultraspin's claims are summarised in Table 12 below.

Table 12 Hydrocyclone Treatment Performance as Claimed by Spinifex/Ultraspin

Parameter	General Hydrocyclone Literature [2]	Case Study - Peerless Holdings, Victoria	Case Study – A.J. Bush, Qld	Case Study – Australian Meat Holdings, Qld
O&G Removal	75 – 95%	Approx. 96%	Approx. 90%	Approx. 80%
Suspended Solids Removal	65 – 75%	Approx. 96%	Approx. 85%	Approx. 75%

The key benefits of the hydrocyclone are:

- achieves high degree of contaminant removal, particularly suspended solids and O&G;
- no chemical additives required;
- very short residence time (in the order of seconds) and consequently very small footprint; and
- high quality fat-rich stream (i.e. low FFA concentration due to short residence time).

6. Technical Comparison with Other Technologies

6.1 Save-Alls

The Save-all is the most basic of the fat removal/recovery technologies. A typical Save-all consists of a large (usually long rectangular) tank, with sufficient detention time to allow free oil and grease to float to the surface. The floated material is then recovered using a chain and flight surface scraper arrangement. Settled solids are also removed by a similar bottom scraper.

Shown in Figure 11 below are some photos of a typical Save-all, as operating at Meat Processing Plant No.3.

Figure 11 Save-all at Meat Processing Plant No.3

The treatment efficiency of a Save-all is typically in the following ranges [2,14]:

- COD removal – approx. 20 – 25%;
- TSS removal – approx. 50 – 60%; and
- Oil & grease removal – approx. 50 – 80%.

More advanced save-all systems, with longer retention times, better skimming and scraping systems and internal recycles may achieve better results.

There are other oil & grease removal technologies available, that are based on gravity separation alone – such as Coalescing Plate Separators, Vertical Gravity Separators and the traditional triple interceptor pit. However, like the Save-all, the treatment efficiency of these systems is quite limited, and therefore are typically used in small applications only (e.g. restaurants, wash bays etc.).

6.2 Dissolved Air Flotation Units

Dissolved Air Flotation (DAF) is a separation technology that utilises micron-size air bubbles (~10 - 100μm diameter) to float suspended solids and O&G particles present in wastewater to the surface. DAF is a well-developed technology with applications in a wide variety of industries, including meat processing.

[14] Grant, P.E. (undated). "Treatment of Fatty Effluents", prepared for Unilever Ltd (Engineering Division).

In a typical DAF process, part of the liquor from the bottom of the DAF tank is withdrawn and pumped to a Saturator Vessel by Pressurising Pumps (at approx. 300 – 600 kPa). Compressed air is dissolved into the liquor in the Saturators. The supersaturated liquor is then fed back into the main DAF vessel, where the bubbles are released (under lower pressure) and attach themselves to the influent sludge and O&G particles, imparting buoyancy. This causes the solids and O&G particles to rise to the surface, where they can be removed via surface scrapers.

The size of the bubbles formed in the DAF greatly affects the performance of the unit, with bubbles smaller than 100µm considered the most efficient. Bubbles of 20 – 50µm diameter are considered best for the recovery of fats and oils. At these small bubble diameters, DAFs are also capable of removing some emulsified oil & grease.

It is also fairly common to add coagulants and flocculants to assist in the flotation and sedimentation processes. These added chemicals can significantly enhance the effectiveness of the DAFs, but also add considerably to operational costs.

With a well-adjusted chemical dosing regime and suitable operating attendance, a DAF will likely achieve [2,14,15,16,17]:

- COD removal – approx. 30 – 90%;
- TSS removal – approx. 50 – 90%; and
- Oil & grease removal – approx. 80 – 95%.

With no chemical dosing, DAF performance decreases slightly:

- COD removal – approx. 30 – 40%;
- TSS removal – approx. 50 – 65%; and
- Oil & grease removal – approx. 60 – 80%.

Shown below in Figure 12 is a schematic diagram of a typical DAF unit.

[15] FSA Environmental (April 2002). “Case Study 11 – Dissolved Air Flotation”, *Solid Separation Systems for the Pig Industry*.

[16] Lovett, D.A., S.M. Travers, (1986). “Dissolved Air Flotation for Abattoir Wastewater”, *Water Research*, vol.20(4), p.421-426.

[17] Page, I.C. *et al*, (1997). “Abattoir Wastewater Treatment Plant Nitrifies at Low Temperatures: A Case Study”, *Proceedings of 1997 American Society of Agricultural Engineers Annual International Meeting*, Minneapolis.

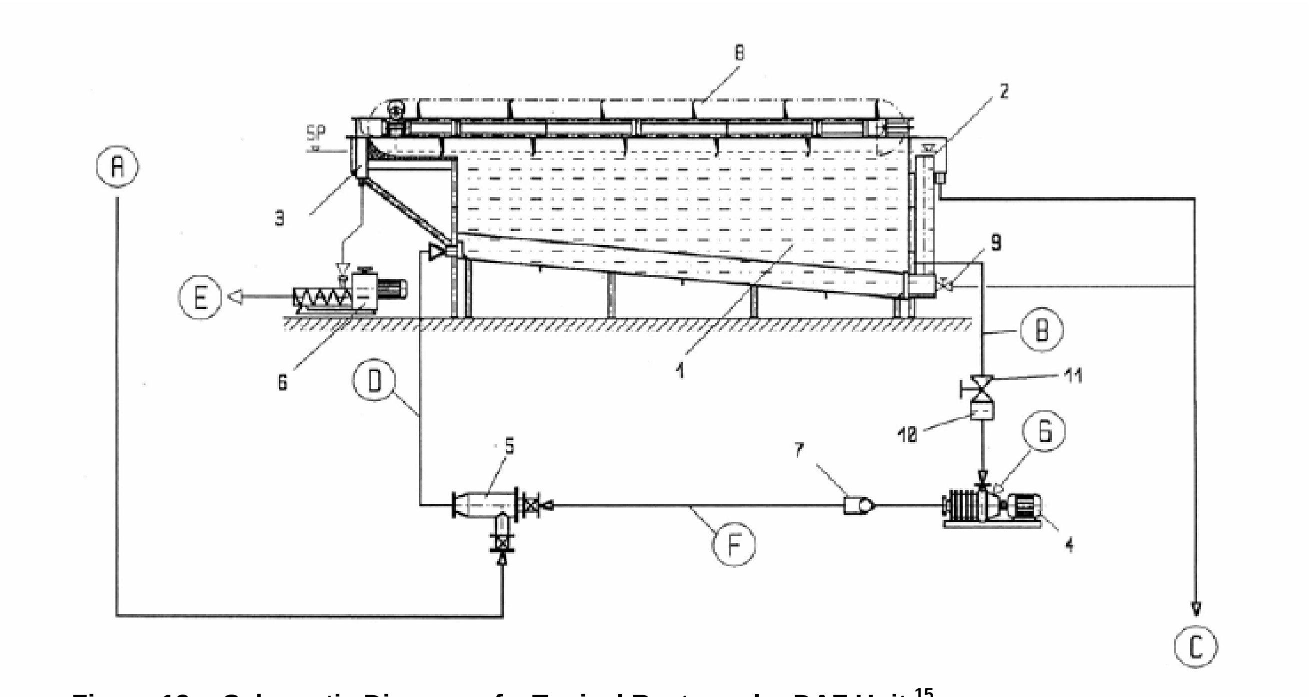

Figure 12 Schematic Diagram of a Typical Rectangular DAF Unit [15]

6.3 Induced Air Flotation Units

Induced Air Flotation (IAF) is another separation technology based on flotation. Originally, the technology was developed for the recovery of minerals in mineral processing plants, but has since been adapted for applications in industrial wastewater treatment, such as meat processing plants [18, 19, 20].

The wastewater is introduced to the system through a vertical downcomer. A recycled effluent stream is used to induce airflow into the top of the downcomer. The effluent is passed through an orifice to produce a simple liquid jet – the kinetic energy of the jet induces air (and coagulants and flocculants, if required) to flow into the top of the downcomer.

Air bubbles present in downcomer are entrapped within the floc structures that form in the wastewater, and the resulting sludge floats to the surface of the cell.

The following treatment efficiencies, with polymer dosing, have been reported, based on a case study at a poultry processing wastewater treatment plant [21]:

- COD removal – approx. 80%;
- TSS removal – approx. 90%; and
- Oil & grease removal – approx. 95%.

Shown in Figure 13 below is a schematic illustration of a typical IAF unit.

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[18] Jameson, G.J., (1999). "Hydophobicity and floc density in induced-air flotation for water treatment", *Colloids and Surfaces A*, vol. 151, p.269-281.

[19] Atkinson, B.(undated). "Innovations in Trade Waste Treatment High Rate Attached-Media Aerobic Biological Treatment and Induced Air Flotation for Biomass Removal", http://www.environmental.com.au/solutions/water/?f=148, accessed 15/8/2003.

[20] Atkinson, B.(undated). "Innovations in Dairy Effluent Treatment High Rate Attached-Media Aerobic Biological Treatment Removal of Biomass by Flotation", http://www.environmental.com.au/solutions/water/?f=149, accessed 15/8/2003.

[21] *EGL Jetflote – Jameson Cell: Nerang Park Poultry Wastewater Treatment Plant*, http://www.bnm.ie/downloads/nerang.pdf, accessed 20/8/2003.

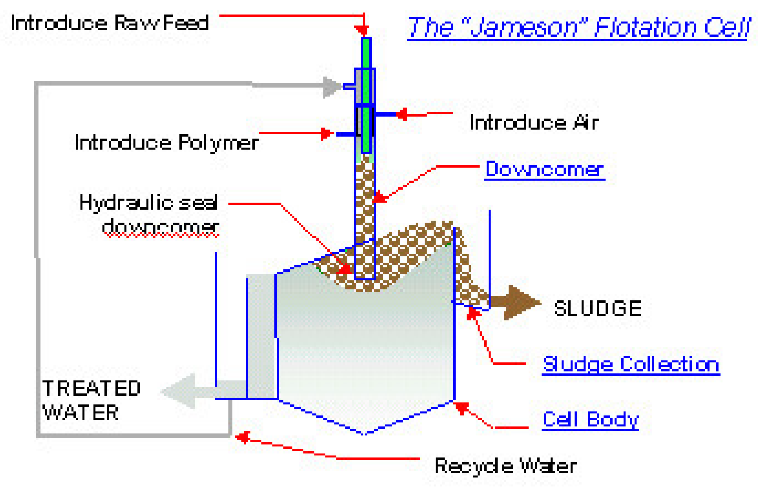

Figure 13 Schematic Diagram of a Typical IAF Unit [22]

6.4 Induced Cyclonic Separation (IC-Sep)

Induced Cyclonic Separation (IC-Sep) technology is based on traditional DAF technology, but uses a different approach to dissolve the air into the feed stream. Whereas traditional DAF supersaturates a side stream of the main flow in a pressure vessel, IC-Sep uses hydrocyclones to dissolve air into the wastewater.

The feed to the flotation cell is first passed through a positive displacement pump, where free air is entrained with the flow. The combined flow is then fed to the IC-Sep unit, where the high pressures and forces associated with the hydrocyclone cause the entrained air to fully dissolve in the liquid flow. Manufacturers claim this can lead to a five (5) fold increase in the volume of dissolved air in the flow, when compared to traditional DAF units.

The following treatment efficiencies, with chemical dosing, have been reported, based on a meat processing plant case study [23]:

- COD/BOD removal – approx. 90% ;
- TSS removal – approx. 98%; and
- Oil & grease removal – approx. 99%.

[22] http://www.environmental.com.au/solutions/water/jameson_call_iafdaf, accessed 15/8/2003.

[23] McKenzie, D. (1999). *A Novel Approach to Wastewater Treatment: The Induced Cyclonic Separator (IC-SEP)*, http://www.acquagroup.com/Assets/English/Documents/Brochures/ACQUA%20ICSEP%20SALES.pdf, accessed 15/8/2003.

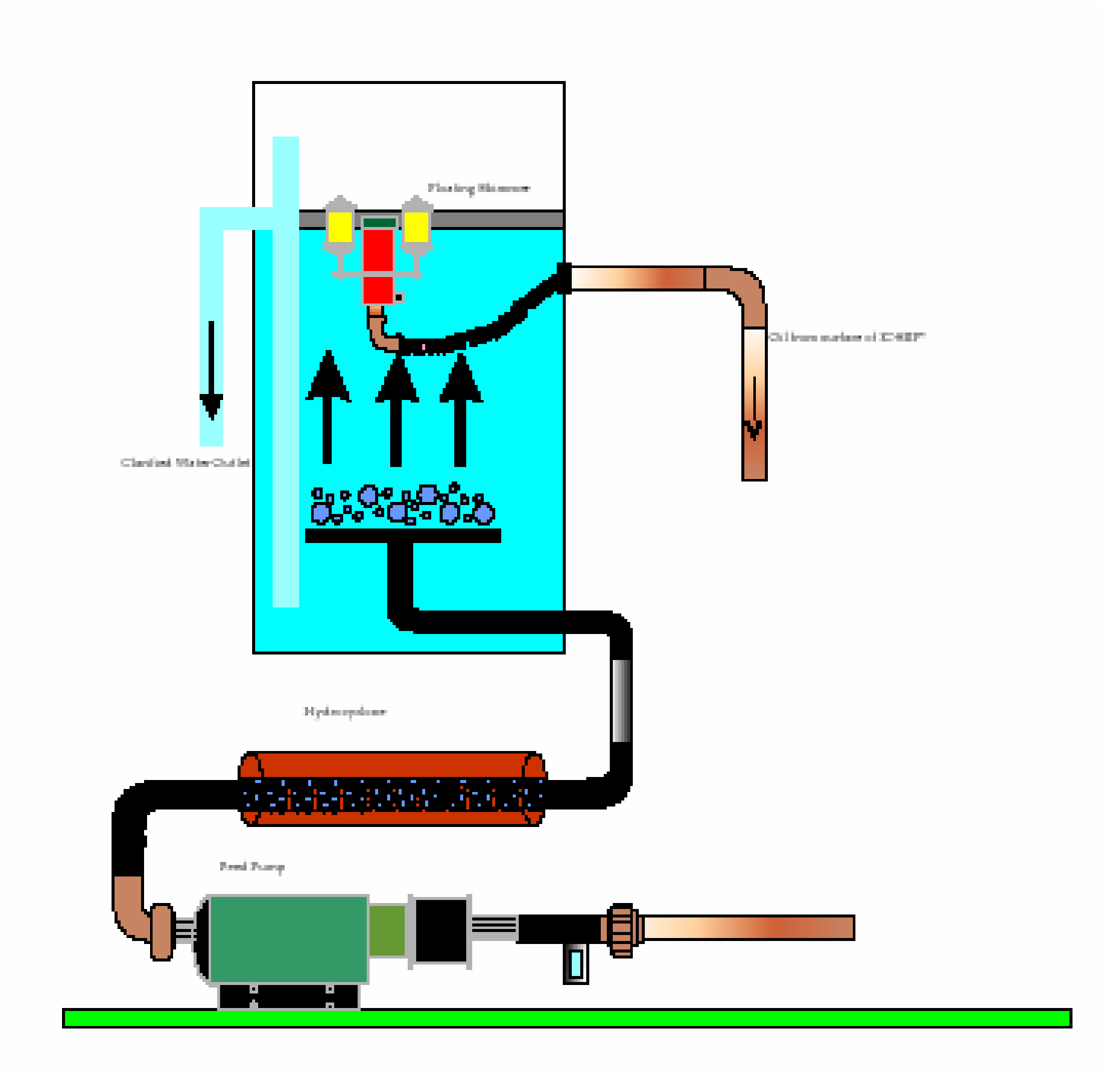

Figure 14 Schematic Diagram of an IC-Sep Unit [24]

[24] acqua (undated), *The Induced Cyclonic Separator (IC-SEP)*, http://www.acquagroup.com/Assets/English/Documents/Brochures/ACQUA%20ICSEP%20SALES.pdf, accessed 15/8/2003.

6.5 Summary of Treatment Technology Comparison

6.5.1 Treatment Efficiencies

Shown below in Table 13 is summary comparison of the five different fat removal technologies investigated in this study.

Table 13 Treatment Efficiencies of O&G Removal Technologies

Technology	COD/BOD Removal	SS Removal	O&G Removal
Save-all	20 – 25%	50 – 60%	50 – 80%
DAF – without chemical dosing	30 – 40%	50 – 65%	60 – 80%
DAF – with chemical dosing	30 – 90%	50 – 90%	80 – 95%
IAF – with chemical dosing	approx. 80%	approx. 90%	approx. 95%
IC-SEP – with chemical dosing	approx. 90%	approx. 98%	approx. 99%
Hydrocyclone *	-	65 – 75%	75 – 95%
Hydrocyclone #	10 – 30%	15 – 60%	40 – 90%

* Removal efficiencies, as reported by Spinifex (Ultraspin) [2]

Removal efficiencies, as determined from GHD's sampling program

This table clearly illustrates that, in terms of treatment performance, the hydrocyclone compares quite well to the traditional technologies of Save-alls and Dissolved Air Flotation (without chemical dosing). Not surprisingly, the operation of the removal technologies with chemical dosing (e.g. polymers, iron salts etc.) leads to a marked improvement in treatment efficiency. Based on the survey above, it is apparent that only with a well-adjusted chemical dosing regime, can treatment efficiencies in the order of 90 – 95% be obtained.

The key technical advantage for the hydrocyclone technology is its ability to achieve a high level of contaminant removal with an extremely short residence time.

The other technologies discussed above all basically rely on natural flotation processes to achieve separation on density difference. In the case of the more sophisticated technologies, this process is accelerated through the use of dissolved air. However, they all still require residence times in the order of minutes and hours to achieve the necessary dissolution, flocculation and disengagement upon which they rely.

On the other hand, hydrocyclones do not rely on flotation. Hydrocyclones use naturally induced centrifugal force to achieve separation on density difference. These forces are significantly stronger (in the order of 1000 g) than buoyancy forces acting in the other technologies. Consequently, hydrocyclones operate with residence times in the order of seconds and can hence provide a very compact and highly effective solution.

6.5.2 Quality of Recovered Fat

A further advantage of the hydrocyclones' very short residence time is the quality of recovered fat. In the case of the other technologies, the longer residence times allows the collected fat to degrade. However, as evidenced by the free fatty acid (FFA) results reported in Table 9 above, it is clear that the recovered fatty material from a hydrocyclone is relatively fresh and can be re-processed in a By-products Plant.

The other technologies discussed above also have the tendency to contaminate the float material with solids. The introduced air bubbles in the wastewater attach themselves indiscriminately to all particles. Therefore, the final float material will contain not only O&G particles, but also other solids particles.

The hydrocyclone (and Save-all) is less likely to collect other heavy solids in the float material because the separation is based purely on density difference. Therefore, the recovered fatty material is more likely to be free from contaminating solids and better suited to reprocessing in a By-products Plant.

6.5.3 Operation and Maintenance Considerations

None of the hydrocyclone installation inspected in this study relied on chemical additives or very high feed pressures to achieve the degree of separation reported. In this respect, the hydrocyclone is very simple, when compared with the traditional DAF units. As a consequence, it also has very low running costs – zero chemical costs and minimal power costs.

The hydrocyclone relies upon only one moving part – the feed pump – and normally only requires periodic operator attention for manual flushing. The operation and maintenance personnel interviewed as part of this study all reported the hydrocyclones to be relatively trouble-free, easy to maintain and operate. There are no complicated start-up and shut-down procedures and there is no lag time in treatment performance upon start-up.

The maintenance troubles reported with the units related to two areas:

1. Handling of the concentrated fat-rich stream.
   - To effectively handle this stream, without clogging, it is necessary to have appropriate lagging and heat tracing for pipes and tanks.
2. Clogging of small diameter inlet and outlet holes on hydrocyclone by hair and grit.
   - One of the installations reported that they had to enlarge the cyclone outlet diameter to avoid excessive blockage by hair and grit. These problems could be avoided by appropriate screening and backflushing.

7. Cost Comparison with Other Technologies

The sampling program undertaken by GHD has demonstrated that the hydrocyclone is comparable to other non-chemical, non-biological O&G removal technologies, in terms of treatment performance. This part of the study examines the cost effectiveness of hydrocyclones.

For this task, a hypothetical case study has been established, loosely based on the smaller hydrocyclone installations at Plant No.2 and No.3. The conditions of the case study are:

- Operating hours: 10.5 hrs/d, 5d/week, 50 weeks/yr;
- Raw wastewater flow 10,000 L/hr;
- COD concentration = 3,500 mg/L;
- Total suspended solid concentration = 1,500 mg/L; and
- O&G concentration = 500 mg/L

The case study investigates both capital and operating and maintenance (O&M) costs for the various technologies. These are presented below in Table 14, both in absolute terms and specific terms (e.g. capital cost per tonne of O&G removed per year). This is intended to illustrate not only the likely overall total costs, but also the effectiveness or “value for money” to be expected from each technology. Removal percentages are based on the estimates summarised in Table 13 above.

The cost estimates presented in this section have been developed for the purposes of comparing options only. The scope and quality of the works has not been defined and therefore the estimates are not warranted by GHD. These estimates are typically developed based on cost curves, budget quotes for some equipment items, extrapolation of recent similar project pricing and GHD experience. The accuracy of the estimates is not expected to be better than about ± 40%.

Detailed calculations are attached in Appendix D.

Table 14 Cost Comparison with Other Technologies – A Case Study

	Save-all	**DAF** (with no chemicals)	**DAF**	**IAF**	**IC-Sep**	**H/cyclone**
Capital Costs						
Total	$20,000	$50,000	$80,000	$70,000	$115,000	$30,000
$ / tonne COD removed / year	$870	$1,360	$970	$950	$1,390	$1,090
$ / tonne TSS removed / year	$850	$1,950	$2,260	$1,980	$3,070	$1,270
$ / tonne OG removed / year	$1,900	$4,760	$6,420	$5,610	$9,220	$2,540
Operating & Maintenance Costs						
Total	$5,070	$7,420	$15,420	$15,270	$14,690	$5,140
$ / tonne COD removed / year	$8.40	$7.70	$7.10	$7.90	$6.80	$7.10

	Save-all	DAF (with no chemicals)	DAF	IAF	IC-Sep	H/cyclone
$ / tonne TSS removed / year	$8.20	$11.00	$16.60	$16.40	$15.00	$8.30
$ / tonne OG removed / year	$18.40	$26.90	$47.10	$46.70	$44.90	$16.60

This table clearly illustrates the cost-effectiveness of the hydrocyclone in comparison to the other available technologies. In terms of COD removal, it is approximately equal to the other available technologies, however in terms of TSS and O&G removal, it is significantly better value for money, both in capital and O&M costs. This is in keeping with the treatment efficiencies reported above in Table 13. As a physical separation process only, the hydrocyclone is most effective in removing TSS and O&G, but has limited potential for COD (and nitrogen and phosphorus) removal.

The table does also indicate that the Save-all and Hydrocyclone are approximately equal in terms of specific costs. However, as already discussed above, the intensity of the hydrocyclone process means it has a very short residence time and consequently, a very small footprint. The same is not true for a Save-all.

Furthermore, the short residence time of the hydrocyclone means that the fat-rich stream can be recovered and processed in a By-products Plant and hence has some further value. Assuming that the fat-rich stream for the hydrocyclone is recovered with an FFA content of 0.5%, it could be rendered and sold as a high grade tallow (< 1% FFA) for approximately $620 per tonne [13]. None of the other O&G technologies are likely to be able to recover a suitable fatty stream for processing in a By-products Plant. Therefore, the hydrocyclone does have a further advantage in that it recovers a fatty product with an economic value.

8. Conclusions

Through an extensive sampling program across three plants, this study has demonstrated that the hydrocyclone is an effective O&G removal technology for the meat processing industry. Furthermore, by comparison of the sampling program results with literature reports on other O&G removal technologies, this study has also demonstrated that the hydrocyclone can achieve a similar treatment standard for meat processing wastewater as other non-chemical, non-biological technologies.

The results from GHD's sampling program also indicated that there was little additional benefit (in terms of suspended solids removal) to be gained from a two-stage hydrocyclone (i.e. de-oiling hydrocyclone, followed by de-sanding hydrocyclone). Additional solids removal/recovery due to the de-sanding stage was found to be in the order of 10%. This result is based upon trials at only one reference site.

An examination of the capital and operating and maintenance costs of hydrocyclones, in comparison to other technologies also showed them to offer significant advantages. In particular, the specific cost (i.e. $ per tonne removed) for suspended solids and O&G removal in hydrocyclones is significantly lower than the traditional dissolved air flotation O&G treatment technology.

The results of the sampling program and the comparison with other technologies is summarised below.

Table 15 Summary of Hydrocyclones versus Other O&G Removal Technologies

	Save-all	**DAF** (with no chemicals)	**DAF**	**IAF**	**IC-Sep**	**H/cyclone**
Treatment Efficiency						
COD/BOD	20 – 25%	30 – 40%	30 – 90%	~ 80%	~ 90%	10 – 30%
SS	50 – 60%	50 – 65%	50 – 90%	~ 90%	~ 98%	15 – 60%
O&G	50 – 80%	60 – 80%	80 – 95%	~ 95%	~ 99%	40 – 90%
Nitrogen	-	-	-	-	-	10 – 25%
Phosphorus	-	-	-	-	-	10 – 25%
Capital Costs						
$ / tonne COD removed / year	$870	$1,360	$970	$950	$1,390	$1,090
$ / tonne TSS removed / year	$850	$1,950	$2,260	$1,980	$3,070	$1,270
$ / tonne OG removed / year	$1,900	$4,760	$6,420	$5,610	$9,220	$2,540
Operating & Maintenance Costs						
$ / tonne COD removed / year	$8.40	$7.70	$7.10	$7.90	$6.80	$7.10
$ / tonne TSS removed / year	$8.20	$11.00	$16.60	$16.40	$15.00	$8.30
$ / tonne OG removed / year	$18.40	$26.90	$47.10	$46.70	$44.90	$16.60

The key benefits of hydrocyclones can thus be summarised as:

- Achieves high degree of contaminant removal, particularly suspended solids and O&G;
- No chemical additives required;
- Very short residence time (in the order of seconds) and consequently very small footprint;
- High quality fat-rich stream (i.e. low FFA concentration due to short residence time), which may have a recoverable economic value as a high-grade tallow;
- Minimal operating and maintenance costs; and
- Very capital cost-effective, particularly in specific terms of $ per tonne of suspended solids and O&G removed.

- Appendix D

Cost Comparison Calculations

Meat and Livestock Australia

PRENV.022 - Assessment of Hydrocyclones for Fat Removal

Cost Comparison Case Study

Case Study Conditions:

Operation:	10.5	hrs/d
	5	d/wk
	50	wk/yr
Flow:	10000	L/hr
COD conc.:	3500	mg/L
TSS conc.:	1500	mg/L
O&G conc.:	500	mg/L

Technologies		**Save-All**	**DAF** (no chemicals)	**DAF**	**IAF**	**IC-Sep**	**Hydrocyclone**
Operation	hrs/yr	2625	2625	2625	2625	2625	2625
Flow	ML/yr	26.25	26.25	26.25	26.25	26.25	26.25
Raw Conc.							
COD	t/yr	91.9	91.9	91.9	91.9	91.9	91.9
TSS	t/yr	39.4	39.4	39.4	39.4	39.4	39.4
O&G	t/yr	13.1	13.1	13.1	13.1	13.1	13.1
Removal							
COD	%	25%	40%	90%	80%	90%	30%
TSS	%	60%	65%	90%	90%	95%	60%
O&G	%	80%	80%	95%	95%	95%	90%

Treated Conc.							
COD	mg/L	2625	2100	350	700	350	2450
TSS	mg/L	600	525	150	150	75	600
O&G	mg/L	100	100	25	25	25	50

Capital Costs							
Equipment Cost		$20,000	$50,000	$80,000	$70,000	$115,000	$30,000
Specific Capital Costs							
$/ML treated/yr		$762	$1,905	$3,048	$2,667	$4,381	$1,143
$/t COD removed /yr		$870	$1,360	$970	$950	$1,390	$1,090
$/t TSS removed /yr		$850	$1,950	$2,260	$1,980	$3,070	$1,270
$/t O&G removed /yr		$1,900	$4,760	$6,420	$5,610	$9,220	$2,540

Operation & Maintenance Costs							
Power	kWhr/yr	9188	21656	37406	30188	34125	7875
Feed Pump	kW	3.00	3.00	3.00	3.00	3.00	3.00
Recycle Pump	kW		4.00	4.00	4.00	4.00	
Compressor	kW		0.75	0.75			
Dosing Pumps	kW			3.00	1.50	3.00	
Mixers	kW			3.00	3.00	3.00	
Scrapers	kW	0.50	0.50	0.50			
Cost	$/kWhr	$0.10	$0.10	$0.10	$0.10	$0.10	$0.10
	$/yr	$919	$2,166	$3,741	$3,019	$3,413	$788

Chemicals	$/ML	$0.00	$0.00	$37.47	$101.16	$12.49	$0.00
	$/yr	$0.00	$0.00	$983.48	$2,655.39	$327.83	$0.00
Operation	hrs/d	0.5	0.5	1.0	1.0	1.0	0.5
	$/yr	$3,750	$3,750	$7,500	$7,500	$7,500	$3,750
Maintenance	$/yr	$400	$1,500	$3,200	$2,100	$3,450	$600
TOTAL	$/yr	$5,070	$7,420	$15,420	$15,270	$14,690	$5,140
Specific O&M Costs							
$/ML treated/yr		$193	$283	$587	$582	$560	$196
$/t COD removed /yr		$8.40	$7.70	$7.10	$7.90	$6.80	$7.10
$/t TSS removed /yr	$	$8.20	$11.00	$16.60	$16.40	$15.00	$8.30
$/t O&G removed /yr		$18.40	$26.90	$47.10	$46.70	$44.90	$16.60