PHOSPHORUS REMOVAL FROM MEAT PROCESSING WASTEWATER: INNOVATION IN PROCESS DESIGN

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ABSTRACT

A large meat and meat by-product processing plant in Southland was required to substantially reduce phosphorus from its effluent to allow continued discharge of treated wastewater into an inland river.

Up to 14,000 m^3/d of effluent generated from the processing plant undergoes physico-chemical treatment. In order to provide for phosphorus removal various treatment and disposal options were considered. The high capital costs of many of the options would have threatened the ongoing viability of the processing plant at the site.

An innovative solution was implemented using the existing physico-chemical treatment system to achieve phosphorus reduction of more than 95% resulting in dissolved reactive phosphorus concentrations well below 1 mg/L in the treated waste streams.

The treatment process implemented at the site involved waste separation and chemical treatment through a retrofit of the existing dissolved air flotation (DAF) plant into a DAF in series system, This allowed the site to meet the new discharge standards within the stringent economic criteria. The method is currently patent pending.

KEYWORDS

Phosphorus removal, Wastewater, Meat processing effluent, DAF in Series, Dissolved air flotation

1 INTRODUCTION

The meat processing industry is the second largest export income earner in New Zealand. It accounts for around 30% of the total primary sector export value. New Zealand is the worlds leading sheep meat exporter and the fourth largest beef exporter.

The processing of meat and meat by-products requires large quantities of potable water, and nearly all of this is discharged as high strength organic, nutrient (nitrogen and phosphorus), fat and microbial contaminated effluent. Many of the processing plants are rural based and therefore require on-site treatment with discharge limits that are becoming tighter as community expectations increase for better treated wastewater discharges, especially into surface water.

A large integrated meat processing facility in Southland responded to the tightening environmental limits when it started environmental investigations in 2002 for a new resource consent to allow continued discharge of treated wastewater to an inland river.

The meat processing plant in this case study generates up to 11,000 m^3/d of effluent through beef, sheep and by-products processing including meat rendering, fellmongery and pelts. The on-site wastewater treatment train involves primary screening from various process areas, save-all and advanced chemical treatment using acid precipitation and separation of precipitate using dissolved air flotation (DAF). Up to 14,000 m^3/d of wastewater, including treatment equipment backwash and air saturated water (whitewater) utilised in the DAF, is then discharged into surface water.

2 DEVELOPMENT OF PHOSPHORUS REMOVAL OPTIONS

2.1 DRIVERS FOR PHOSPHORUS REDUCTION

In 2002, the meat company conducted several rounds of consultation with the various community stakeholders and regulatory groups in Southland in order to identify a strategy for the upcoming consenting round. From this exercise it was determined that the primary water quality driver was phosphorus, especially dissolved reactive phosphorus (DRP) and the secondary water quality driver was bacteria reduction to allow continued discharge of treated wastewater to the surface water.

Phosphorus had been identified as the key contaminant in the wastewater and has been recognised as the "cause" of periphyton growth in the receiving environment surface water. Phosphorus had also been given a high priority after preliminary consultation between the meat company and the Regional Council and also in the Regional Council's compliance monitoring reporting. Department of Conservation and Fish & Game had also confirmed that phosphorus was also the "the primary concern" for the receiving environment surface water.

Given the early signals provided by various stakeholders, the meat company considered that to allow continued discharge to the surface water, DRP concentration in the treated wastewater would need to be reduced to around 1 mg/L.

The meat company was granted resource consents in November 2003 with DRP compliance limit of 14.4 kg/d based on a corresponding maximum discharge volume of 14,400 m^3/d. Given that the peak discharge was around 14,000 m^3/d, this effectively set DRP concentration in the discharged treated wastewater to be around 1 mg/L to ensure compliance coinciding with peak production. This meant that DRP removal had to be more than 95% from previous discharge levels during peak processing.

In addition to the reduction of DRP, the discharge from the processing plant had to be of high clarity so that in future microbial disinfection could be implemented.

2.2 PHOSPHORUS CONTROL TECHNOLOGIES

There are currently two widely used processes for removing phosphorus from wastewater (Valsami-Jones, 2004). These are:

1. Chemical phosphorus removal (CPR) processes which are based on the addition of a metal salt or lime to the wastewater, causing the precipitation of an insoluble phosphate, which can be separated out of the wastewater; and

2. Biological phosphorus removal (BPR) processes in which conditions are created that encourage certain types of bacteria to take up excessive amounts of phosphorus. The bacteria are then removed from the treatment process before they have time to release this phosphorus.

2.2.1 MECHANISM OF CHEMICAL PHOSPHORUS REMOVAL

Phosphorus removal by precipitation with metal salts such as aluminium, iron and calcium, can achieve final phosphorus concentrations below 1 mg/L. To achieve lower phosphorus concentrations, increasingly high doses of metal salts are required, often in excess of two times the stoichiometric requirements. Lime may also be used as a source of calcium ions which form calcium phosphate and precipitation occurs above a certain pH. The two most common metal salts used for phosphorous removal are aluminium compounds and iron compounds.

Aluminium compounds include alum (hydrated aluminium sulphate), sodium aluminate, aluminium chlorohydrate, and poly-aluminium chloride (PAC). Two of these aluminium compounds are readily available in New Zealand; alum and PAC. Aluminium salts are more susceptible to pH variation than iron salts. Alum is available in NZ in solid granular form ($Al_2[SO_4]_3.14H_2O$) which contains 9.1% soluble aluminium as Al and 17% soluble aluminium as Al_2O_3. It is also available at a 47% solution which contains 4.3% Al by weight. In order to effect phosphorus removal, a ratio of around 9.6 kg alum/kg P (Al:P at 0.87:1) removed is required. In practice, the quantities of alum required are higher than stoichiometric because of competing reactions, which vary with the wastewater. PAC is available in NZ at 34% solution, which contains 5.3% Al by weight and will require similar proportions as liquid alum for phosphorus precipitation.

Iron compounds include ferric chloride, ferric sulphate, ferrous chloride and ferrous sulphate. Ferric chloride and ferrous sulphate are the most commonly used and are readily available in New Zealand. Ferric chloride is available in New Zealand as a 41% solution and contains 14% Fe by weight. To achieve phosphorus removal a weight ratio of $FeCl_3$:P of more than 5.2:1 is required. Ferrous sulphate is available in New Zealand as ferrous sulphate heptahydrate 98% solution. It contains 19.7 % Fe by weight and a ratio similar to ferric chloride is required to effect P removal.

Calcium based compounds include burnt lime (CaO) and hydrated lime ($Ca[OH]_2$). The addition of lime results in the precipitant hydroxylapatite ($Ca_{10}[PO_4]_6[OH]_2$). The best residuals are achieved at higher pH. Generally, a lime dosage to achieve phosphate removal approximately equals 1.5 times the total alkalinity (mg/L $CaCO_3$). The quantity of lime required for phosphorus removal is controlled by the amount of lime required to adjust the pH as this is far greater than the quantity of calcium to react with the phosphorus. Calculations for lime usage can therefore only be determined by carrying out pH adjustment tests.

2.2.2 BIOLOGICAL PHOSPHORUS REMOVAL

Biological processes for the removal of phosphorus have been developed during the last twenty years and are now beginning to compete with the more conventional physical/chemical approach of precipitation with metal salts. Biological phosphorus removal (BPR) plants commonly involve a number of different stages of treatment, including anaerobic, aerobic and anoxic zones and require liquid residence times of around 24 hours. They are thus large plants with a significant capital and operating cost.

BPR relies on conditions existing in the biological reactors of the treatment plant, which encourage certain micro-organisms to take up excess phosphorus. These conditions prevail when there is plenty of readily available food (measured as soluble chemical oxygen demand) and an absence of oxygen or nitrates. These conditions are created by cycling aerobic and anaerobic conditions, enabling these organisms to take up excess phosphorus during the aerobic cycle to store energy. The phosphorus is removed from the process by removing a percentage of the organisms towards the end of the aerobic phase when they have saturated themselves with phosphorus.

BPR produces varied results and is difficult to manage and operate to achieve consistently high removal rates. Generally, when operated under favourable conditions enhanced BPR plants are able to remove 80 – 90% of influent phosphorus (McGrath & Quinn, 2004) and therefore removal to concentrations of phosphorus less than 1 mg/L is difficult to achieve. Results vary from plant to plant and it is extremely difficult to predict what phosphorus removal rate will be achieved. For this reason many BPR plants have facilities for augmenting the system by the addition of chemicals to assist in phosphorus precipitation when the biological process is not achieving the required result. In addition to this, the plant has to be kept operational and can’t be switched on and off. However, on average and with good operational control, BPR plants treating effluent with low levels of phosphorus in the influent can reduce phosphorus concentrations to less than 1 mg/L, although some plants with insufficient readily assimilable carbon in the feedwater have difficulty in consistently achieving this level.

2.3 TREATMENT FEASIBILITY STUDIES

As part of preliminary assessment a multitude of treatment options and combination of options that would assist in the removal of phosphorus were identified and outlined. The options were initially screened and six broad options were identified.

While phosphorus treatment options were being screened, a parallel investigation resulted in discounting the use of land as a final receiving environment because studies on land suitability had concluded that much of the land in the vicinity of the processing plant was not suitable for long-term land disposal. This resulted in examination in detail of the on-site treatment and continued disposal of the treated wastewater into the inland river.

In addition to this, the location of the meat processing plant presented future wastewater treatment footprint constraints due to lack of space in the vicinity of the plant and the seasonal nature of processing with no shoulder processing period and the peak wastewater generation coinciding with low river flows.

The discharge criterion was also based on achieving a best practicable option (BPO) where the DRP concentration in the final discharge is around 1 mg/L. This criterion did not attempt to achieve a minimum standard for the in-stream phosphorus concentration in the river. Discharging DRP at 1 mg/L would elevate the river DRP concentration by 0.007 mg/L based on the mean annual low flow (20.24 m^3/s) and by 0.016 mg/L based on the lowest river flow on record (9.26 m^3/s). There was also no consensus on the appropriate water quality standard for DRP in the receiving water for the site, therefore the meat company relied on the BPO approach.

2.3.1 SHORT LISTING OF TREATMENT OPTIONS

Six options had been investigated for feasibility of implementation and corresponding capital, operating and net present value cost analysis. These options included:

A. *Full Flow CPR*: Enhanced chemical phosphorus removal in the existing DAF treatment plant, either via pre-DAF precipitation (Option A1) of primary effluent or post-DAF precipitation (Option A2) of DAF treated effluent on the total waste stream;

B. *Green Waste CPR*: Segregation of "green waste streams" and diverted for enhanced chemical phosphorus removal either via pre-DAF precipitation (Option B1) or post-DAF precipitation (Option B2) and solids separation using additional clarifiers and finally discharged to surface water;

C. *Full Flow BPR*: Biological phosphorus removal from the whole waste stream by replacing the existing DAF treatment plant and discharging to the surface water (Option C); and

D. *Green Waste BPR*: Biological phosphorus removal from the "green waste streams" through a separate BPR plant and discharging the combined wastewater into the surface water (Option D).

The green waste streams were identified as those waste streams generated from specific processing areas that contained a higher amount of phosphorus. These waste streams generally included wastes sources from stockyards, rendering, gut-cutting operations and casings.

The budget/conceptual design capital costs estimates (±30%) ranged between $1.8M - $10.6M. A net present value (NPV) was undertaken for all options using an operating life of 20 years. The NPV costs for the options were estimated to be between $12.2M - $21.3M. Options B1 and B2 were ranked with the lowest NPV costs and were recommended to be investigated further.

In order to progress on establishing whether Option B1 or Option B2 would be taken further for refinement of design and capital costs, a series of bench scale trials were conducted to determine chemical use requirements and the suitability of solids separation either through primary or secondary clarification. Following, the solids separation trial, Option B2 was modified (see Figure 1) with the development of use of DAF in series (Patent Pending) (Khan, 2005). This change resulted in a significant reduction of capital costs for the upgrade.

3 UPGRADE IMPLEMENTATION PLAN

3.1 WASTE STREAM SEPARATION WORK

In order to allow effective use of modified Option B2, the meat company was required to separate the green waste streams from the non-green waste streams. During the initial waste survey in May 2002, the monitored waste streams that were identified as being green accounted for 36% of the total plant flow. The meat company identified that a large proportion of the volume of the wastewater in the green effluent stream was contributed by sheep wash facilities and did not substantially contribute to phosphorus loading. In addition to this, during the 2002 survey, the rendering plant was identified as a large contributor of organic and oil & grease load. A separate physico-chemical DAF system with acid treatment was installed for the rendering plant flow to recover a large amount of oil & grease.

Following the initial waste separation work, a further waste survey was undertaken in April 2005 and it was identified that nearly all the phosphorus (especially DRP) was contained in waste streams contributing to 16%

of the total volume of effluent generated at the site. This meant that the footprint of the upgrade of wastewater treatment facilities could be accommodated with minor changes to the existing wastewater process train.

A summary of wastewater characteristics in the initial survey in 2002 and the waste survey undertaken in 2005 shows how the phosphorus load from the contributing streams was captured in 16% of the total effluent volume generated.

Table 1: Green Effluent Stream Separation Assessment during Waste Surveys

Parameter	**Percent of Total Flow/Load in Green Waste Streams**	
	May 2002	**April 2005**
Flow	36	16
Total suspended solids	98	58
Biochemical oxygen demand	85	43
Total chemical oxygen demand	73	55
Total Kjeldahl nitrogen	69	52
Total phosphorus	86	86
Dissolved reactive phosphorus	100	98
Oil and grease	91	47

Notes:

1. *May 2002 survey shows the high contribution of contaminant loads from the rendering plant as the amount of organic matter and oil & grease is high.*
2. *The total suspended solids are generally contributed from the sheep wash facilities as a lot of silt/dust is washed from sheep prior to slaughter.*
3. *A slight decrease in DRP is as a result of separation of the sheep wash water into the non-green waste stream.*

Whilst the meat company recognised the opportunity to undertake further waste separation from some specific in-plant processing areas, there seemed to be little advantage in continuing with this costly separation work as the amount of DRP recovered in the initial green waste stream separation was well above the requirements to effect DRP removal after treatment.

3.2 INNOVATION IN PROCESS DESIGN

3.2.1 SINGLE STEP pH TREATMENT

Much of the protein in meat processing effluents is either colloidal or soluble and, therefore, not recovered by simple physical treatment processes such as sedimentation or dissolved air flotation. Partial purification of meat processing effluents can be effected by adjusting the pH and dosing the effluent with specific protein coagulants to precipitate the soluble proteins (Cooper, 1991). Simple adjustment of pH of an effluent to a pH between 3 and 5 effectively removes many soluble proteins from the effluent.

The meat processing plant in this case study previously utilised this single step form of physico-chemical treatment to remove a large amount of proteins, biochemical oxygen demand and oil & grease. They continue to implement this single step pH treatment for the non-green waste stream after the upgrade.

3.2.2 MIRINZ DOUBLE pH ADJUSTMENT TREATMENT

A variation to the single step pH treatment using acids has been developed by Meat Industry Institute of New Zealand (MIRINZ, now part of AgResearch) to reduce the need to add specific protein precipitants as the chemical treatment costs were deemed to be very high. This led to the development of two-stage pH adjustment process (Cooper et al, 1982a). Two-stage pH adjustment can produce an effluent that is superior to that produced by acidification alone. The essential features of this process are (1) to lower the effluent pH to 3 by addition of sulphuric acid, and then (2) to raise the pH with ether sodium or calcium hydroxide to a pH of between 6 to 9. The use of calcium hydroxide to raise the pH to 9 also has the advantage of removing 75% of the phosphorus in the effluent (Copper et al, 1982b).

The use of the two-stage pH adjustment is most effective for wastes containing high blood concentrations, where acid treatment irreversibly splits haemoglobin into its heme and globin components.

Stephenson (1978) suggested that pH 9 is optimal for flocculation and when a polyelectrolyte is added, the flocculated protein-calcium phosphate aggregates have a high specific gravity, allowing rapid sedimentation to occur. This then allows use of secondary clarification as a method of separation.

This method of physico-chemical treatment is utilised at large meat processing plant in Canterbury, however, the final discharge does not provide significant clarity, a requirement that was set as one of the objectives for the upgrade at the meat plant in this case study.

3.2.3 PDP ACID-ALKALI pH TREATMENT and DAF IN SERIES (Patent Pending)

In recognising the requirement to continue to utilise the physico-chemical treatment plant while enabling removal of nearly all phosphorus, especially DRP, and ensuring that the treated discharge was suitable for future microbial disinfection, Pattle Delamore Partners Limited (PDP) successfully modified the MIRINZ double pH adjustment treatment as follows:

1. Initial acid phase treatment of screened meat processing effluent to a pH of less than 4.5 to remove proteins and harvesting of precipitated solids using dissolved air flotation (DAF);

2. Subsequent alkali phase treatment of acid phase treated DAF effluent to a pH of less than 9.5 using calcium hydroxide to remove DRP and harvesting the solids using another DAF unit in series to the acid phase DAF.

The main difference to the MIRINZ double pH adjustment process was that the DAF float sludge was harvested after acid phase dosing prior to increasing the pH. This resulted in lighter floc formation that had a lower specific gravity and a natural tendency to float rather than settle.

This method of physico-chemical treatment resulted in very low levels of DRP (DRP < 1 mg/L) in the final discharge and has provided a very clear effluent (transmittance 25 – 35% at 254 nm) suitable for disinfection using ultraviolet light. The amount of lime utilised is also lower than the MIRINZ double pH adjustment treatment as the acid phase float sludge is removed reducing the competing consumption of ions by the solids.

The use of aluminium was also discounted as the acid and aluminium ion treated effluent still contains substantial concentrations of soluble chemical oxygen demand, total Kjeldahl nitrogen and more importantly a blood red colour (Russell et al, 1981). The colour in the treated effluent was a significant issue for surface water discharge and future requirement for microbial disinfection.

3.3 UPGRADED PHYSICO-CHEMICAL TREATMENT

The upgrading of the treatment plant was undertaken in 6 key aspects. These included:

1. Pilot plant trials to demonstrate the suitability of DAF in series system and to confirm the basis of design of a full-scale upgrade for the site including microbial disinfection trails to determine the suitability of the use of ultraviolet disinfection from the final discharge from the DAF in series system;

2. Provision of separate acid phase DAF treatment of rendering plant wastewater to reduce the amount of oil and grease and proteins becoming part of the green waste stream;

3. Implementation of waste separation work in all processing areas, conversion of existing intermediate effluent pump stations, separation of green and non-green waste streams. Continued treatment of non-green waste streams through acid phase DAF;

4. Piping of green and non-green waste streams from specific areas into dedicated pump stations, flow separation at primary screening facilities, flow splitting in the saveall, pumping and piping re-configuration for establishing DAF units in series, establishing of acid and alkali dosing process units, associated instrumentation and control; and

5. Undertaking trials for the DAF float sludge dewatering and full-scale upgrade of the solids handling and dewatering facilities. Upgrade of the sand and grit removal system as the waste streams were now separated and required separate handling systems to avoid cross-contamination of each waste stream prior to the removal of phosphorus from the green waste stream.

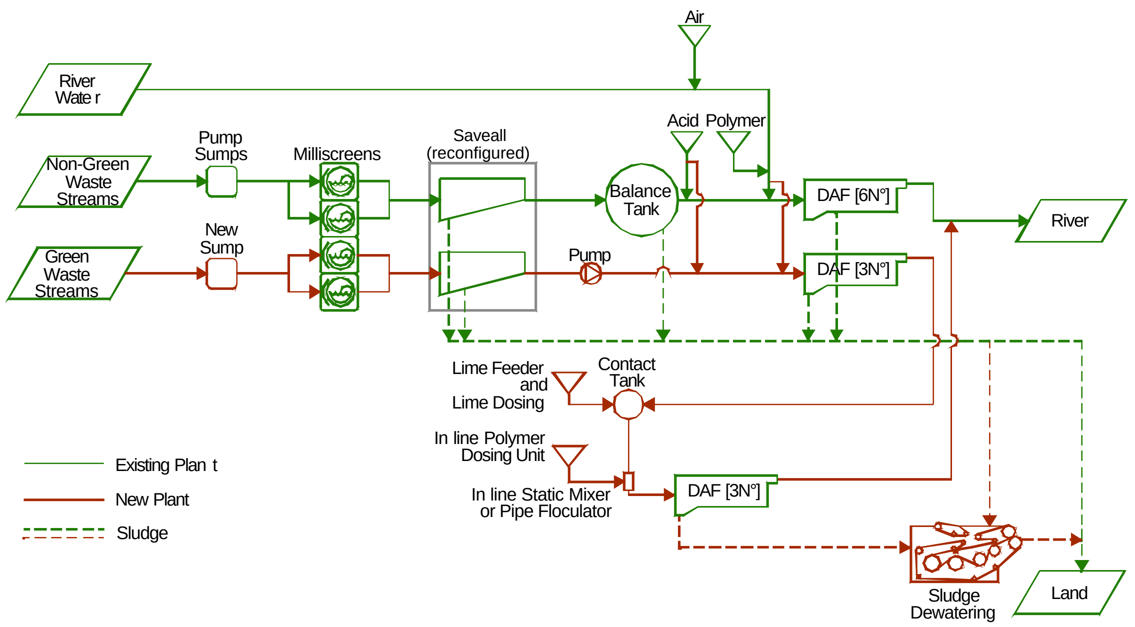
Other in-plant process upgrade included conversion of "wet dump" of paunch content material (PCM) in the beef processing plant into a "dry dump" system with PCM dewatering in the immediate vicinity of the paunch cutting station, preventing mobilisation of PCM through the effluent reticulation system.

The most significant part of the upgrade was that the meat processing plant was able to maintain the same footprint for its main wastewater treatment facility except for moderate changes in process flows and piping re-arrangements. The only substantial upgrades were the installation of a separate small DAF unit for the rendering plant effluent and dedicated dewatering units for PCM at the beef plant and filter belt-press for DAF float sludge handling.

All other upgrades included retrofitting existing pump-stations to handle separated green waste streams and piping to the main treatment plant. The process changes involved the inclusion of lime (alkali) storage and dosing facilities.

The discharge from the non-green acid phase DAF treatment system and the green alkali phase was combined to avoid discharge of a high pH treated wastewater into the surface water. A simplified schematic of the general process layout is given in Figure 1.

Figure 1: Schematic Layout of Upgrade including DAF in Series Plant



3.4 PHOSPHORUS REMOVAL EFFICIENCY

The results from analyses of samples collected during the pilot-scale trial and from full-scale implementation during the commissioning period are summarised in Table 2.

Table 2: Phosphorus Removal Efficiencies using DAF in Series at Pilot & Full Scale

Analyte	**Pilot Scale Trial[1]**			**Full Scale System[2]**		
	Influent (mg/L)	**Discharge (mg/L)**	**Removal (%)**	**Influent (mg/L)**	**Discharge (mg/L)**	**Removal (%)**
Total phosphorus	48.1	8.3	78	99.4	7	93
Total dissolved phosphorus	38.8	1.38	95	85.5	1.64	94
Dissolved reactive phosphorus	30.5	0.43	97	64.2	0.23	99

Notes:

1. *The pilot scale trial results are based on the average of 16 sampling results during April 2004.*
2. *The full-scale plant results are based on 3 sample results during the commissioning period in April 2005.*

Following the waste separation works, the level of DRP in the green waste stream was much higher than at the pilot scale trial level. There was a much better response in treatment in the full scale system because of improved polyelectrolyte contact. It also seemed that the longer contact time in the DAF promoted the maintenance of high pH conditions which effected better DRP reduction.

As a result of the green waste stream separation, the non-green waste streams were found to contribute less than 2% of the DRP load (< 3 kg/d) of the total loads generated at the site. This meant that following combination of the treated green waste stream and the non-green waste streams DRP loads were well below 5 kg/d, well below the compliance limit requirements.

As a result of the separation of green effluent, there was no significant change in the level of sulphuric acid use for the acid phase at around 0.25 kg sulphuric acid per cubic metre of effluent. The amount of lime use in the pilot scale trials was estimated at 0.25 kg lime per cubic metre effluent treated. However, in the full-scale system, the lime usage was around 0.73 kg lime per cubic metre of green effluent treated. The increase in lime usage was a direct result of the concentration of the green waste stream due to the reduction of the water inputs. Despite the increase in lime usage, the total cost of lime to remove the DRP was calculated to be lower than the cost of alum to remove an equivalent amount of DRP.

4 CONCLUSIONS

Faced with a potentially very high capital cost solution for a brownfield retrofit, the meat processing plant in this case study adopted a very innovative method of removing phosphorus while maintaining the final discharge at a very good clarity that would allow it to progress to microbial disinfection using ultraviolet light if required in future.

The double pH adjustment process with sulphuric acid and lime is most effective for wastes containing soluble proteins and high levels of phosphorus as was found in the green waste stream at this meat processing plant. The acid irreversibly splits haemoglobin into its heme and globin components. The calcium ions decrease the solubility of globin and other proteins at higher pH values and the high pH conditions also allow the precipitation of DRP in the presence of calcium ions.

The development of the PDP acid-alkali pH treatment and DAF in series system (patent pending) has resulted in a clearer effluent with less lime usage as the float sludge is harvested after the acid phase. It had also provided significant capital costs savings to the meat processing plant. The additional operating costs for DRP removal is also less than that of alternative metal salts based DRP precipitation. The disposal of DAF float sludge has not changed from previous land disposal based disposal.

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