WASTE MINIMIZATION IN THE POULTRY PROCESSING INDUSTRY-
PROCESS AND WATER QUALITY ASPECTS

Presented at
MISSTAP WORKSHOP
WASTE MINIMIZATION FOR MISSISSIPPI INDUSTRIES
MISSISSIPPI STATE UNIVERSITY

By
Stephen R Gelman, P.E.
Manager, Industrial Process Division

Sheila Scott
Project Engineer

Hal Davis
Project Engineer

CH2M HILL
Montgomery, Alabama 36116

November 9, 1989
INTRODUCTION

The poultry processing industry is a large, water intensive industry. In a typical week in Alabama, up to 15 million birds are processed and Arkansas, Georgia, and North Carolina have similar processing volumes. Mississippi is now one of the top five boiler producing states in the United States with an annual production of 361 million birds in 1988. Because of a typical water usage of 8 gallons per bird processed, the industry is a major water user in the state. With the BOD and suspended solids loads of processing wastes it is fitting that the poultry processing industry be included as part of this waste minimization conference.

Waste minimization is a new term but not a new concept in the poultry processing and other food processing industries. The industry has been characterized by a high degree of water reuse and by-product recovery. My definition of waste minimization will include both water usage and waste loads since the two are related. The industry is by no means at ground zero when it comes to waste minimization. BOD loads and water usage vary significantly across the industry and are dependent on the particular plant circumstances. Although we typically use 8 gal/bird as an average water use, there are plants operating at 5 gal/bird and even some reported at 3 gallons per bird. BOD and TSS loads vary similarly. These figures illustrate that there is an opportunity to reduce water usage and waste loads, given the proper incentive.

This presentation will focus on issues surrounding waste minimization in the live processing industry as well as provide a brief look at the prepared foods segment, mainly cooked chicken products. In addition, I will use a case study to show where waste minimization issues directly affect design and operation of pollution abatement facilities. The case study also reviews water quality issues that require us to examine waste treatment in a new light. This information will also apply to other industries facing more stringent treatment requirements as a result of stiffer water quality regulations.

First let us review the incentives for waste minimization for a poultry processor. The industry is in a precarious position, as are other food and consumer products industries; it can be characterized as being in a three-sided cage. On one side is the USDA with minimum demands for water usage, cleaning and health requirements, and processing procedures. On another side is the consumer demanding an absolutely safe product at a reasonable cost. Finally, on the third side are the environmental regulators with ever tightening limits, new regulations, and pressure to reduce waste loads. The industry, particularly in Mississippi, is characterized by family-owned businesses and is extremely cost competitive. While waste
minimization is an important issue, the owner has to place product integrity and cost as major considerations when implementing waste minimization projects.

With these considerations in mind, what are the incentives for implementing a more comprehensive waste minimization program? First, there is the ever-tightening regulatory environment. With increased emphasis on groundwater and non-point pollution, land treatment may be less favored than in the past. The Clean Water Act Amendments have emphasized toxics, including ammonia and chlorine. Systems may need to be upgraded include nitrification. Waste minimization may be an approach to enable existing facilities to reduce ammonia without addition of new processes. The Clean Water Amendments also are placing the publicly owned treatment works (POTW) under more stringent requirements such as nutrient removal and toxics control. Increased costs of treatment for sludge handling will be passed on to users through higher water and sewer rates putting more pressure on the industrial users to minimize water and waste loads to remain competitive. Processors will have to balance the costs to implement water savings and waste minimization programs against the costs of increased user fees. Point source dischargers (NPDES) will have to trade off more exotic wastewater treatment against in-plant and production changes to reduce waste loads.

Next I would like to present a case study that will discuss not only waste minimization in the poultry processing industry, but also a number of treatment and permitting issues. CH2M HILL, was not involved in the original design but has assisted the industry in implementing process modifications, providing operations assistance, and helping in regulatory liaison. I will also address how other processors have addressed some of these issues to reduce water usage and waste loads. Finally, we will review some aspects of the cooked chicken industry for waste minimization.

PLANT DESCRIPTION

The plant processes up to a maximum capacity of 200,000 birds per day. The process train is typical of most poultry processors. Live birds are unloaded under a covered drive and suspended on a conveyor chain. After they have been killed, the birds are scalded in a hot water tank to assist in defeathering, which is accomplished by mechanical action in which rotating rubber fingers pull off feathers. A flame singes hair and pinfeathers.

The next process step is evisceration, opening and subsequent removal of all inner organs. Edible organs such as heart, liver, and gizzards are harvested in the evisceration process.

Following evisceration, the birds are washed and chilled. Final product is typically packed in ice. Giblets are separately chilled prior to being packed with the bird carcass.

WASTEWATER PRODUCTION

Primary sources of wastewater are from the scalder, which may use fresh water as makeup; from chiller overflow from the evisceration process; and from cleanup. Evisceration flow consists of numerous handwash stations, as well as gizzard splitters, venting machines, and washers. Daily cleanup includes not only washing the plant after shutdown but also cleaning the live bird storage area.

BOD and suspended solids sources are from the same general locations, although blood handling affects BOD loads much more than it does flow.

Detailed waste characterization studies have been done by CH2M HILL at a similar processing facility in Northwest Arkansas. These data illustrate sources of flow and BOD and are shown in Table 1. Major BOD loads come from the scalder and from the evisceration area, as well as from cleanup.

In this particular plant, cleanup accounted for over 20 percent of the BOD load and over 25 percent of the wastewater flow. Impacts of these flows and loading will be discussed in a later section.
Table 1. Wastewater Production and BOD Sources for Poultry Processing

PLANT 'TOTALS

<table>
<thead>
<tr>
<th>Flow, gal/bird</th>
<th>BOD Load, lb/000 birds</th>
<th>TSS Load, lb/000 birds</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.6</td>
<td>60-68</td>
<td>22-24</td>
</tr>
</tbody>
</table>

SOURCES OF FLOW AND BOD

<table>
<thead>
<tr>
<th>Flow</th>
<th>BOD</th>
<th>% of Total BOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>gal/bird</td>
<td>mg/l</td>
<td>Load</td>
</tr>
<tr>
<td>Evisceration Flow, Total</td>
<td>3.3</td>
<td>561</td>
</tr>
<tr>
<td>To Sewer</td>
<td>1.7</td>
<td>1,260</td>
</tr>
<tr>
<td>To Reuse (F)</td>
<td>1.6</td>
<td>1,250</td>
</tr>
<tr>
<td>Scalder Overflow (F)</td>
<td>0.3</td>
<td>890</td>
</tr>
<tr>
<td>Hockers, Pickers, Etc. (F)</td>
<td>0.3</td>
<td>9</td>
</tr>
<tr>
<td>Total Feather Flume</td>
<td>2.3</td>
<td>1,060</td>
</tr>
<tr>
<td>Chiller</td>
<td>0.5</td>
<td>1,060</td>
</tr>
<tr>
<td>Giblet Pumps and Chiller</td>
<td>0.4</td>
<td>890</td>
</tr>
<tr>
<td>Miscellaneous Washes</td>
<td>0.4</td>
<td>9</td>
</tr>
<tr>
<td>Cleanup</td>
<td>2.0</td>
<td>1,200</td>
</tr>
<tr>
<td>Equipment Dumps</td>
<td>0.3</td>
<td>1,200</td>
</tr>
</tbody>
</table>

(F) - Indicates reuse to feather flume.
TREATMENT PLANT DESCRIPTION

A process flow sheet for the original case study treatment plant is shown in Figure 1. Primary treatment was accomplished by coagulation and flocculation followed by settling in a primary clarifier. Coagulation was accomplished with alum and an anionic polymer. Primary effluent overflowed to an earthen aeration basin, and mixed liquor was then pumped to a secondary clarifier. Polishing was provided by chemical coagulation and sedimentation in an accelerator. Accelerator effluent was then aerated prior to chlorination and discharge. Design criteria for the facility are presented in Table 2. Several design deficiencies were evident in the original design. Fit a skimmer was not provided on the primary clarifier. This deficiency necessitated using high chemical doses to make the grease settle. Also, the drying bed area was insufficient to handle both the primary and secondary sludges.

INITIAL PROCESS MODIFICATIONS

OPERATIONAL PROBLEMS

CH2M HILL’s initial involvement was aimed at helping the processor achieve permit compliance for BOD, TSS, and oil and grease and assisting in upgrading the sludge handling facilities. The plant had a mass BOD limit of approximately 300 lb/call based on effluent guideline limits derived from production. Plant water use was excessive, greater than 12 gallons per bird. This excess required an effluent BOD concentration of around 12 mg/l compared to a BOD of 20 mg/l if the plant had been around eight gallons/bird the industry standard at that time. High water use was compounding treatment problems as follows:

- Polymer and alum doses requirements were based primarily on flow, causing increased chemical doses and costs, as well as increased sludge production.
- Clarifier retention times were shorter than design.
- Retention time in the aeration basin was below design level.
- Because of the mass limits, required effluent BOD and TSS concentrations were lower than they would be if the plant were using less water.

Other problems involved sludge handling. Renderers would not accept alum-based primary sludges. The gelatinous primary sludge was difficult to dry, especially given the undersized sand drying beds.

Finally, the aeration basin was not being maintained at a high enough MLSS level to achieve adequate treatment. The result was a high soluble BOD and excessive effluent TSS because of poor settling floc. This plant was obviously a candidate for flow reduction and waste minimization.

WATER USAGE

The initial emphasis was on water use reduction. Increased education of plant personnel and management was the key to reducing water consumption. Since the industry produced its own process water at a surface water treatment facility, reducing water use in processing also reduced costs and demands on the water treatment plant.

Reductions in flow were achieved by numerous actions. These included:

- Use of screened water from the eviscerating flume as makeup water in the feather flume
- Increased attention to hoses and faucets left running
RAW INFLUENT

RAPID MIX

ALUM FEED

SLOW MIX

POLYMER FEED

PRIMARY CLARIFIER

AERATION BASIN

TO SCREEN/LAND OR DIGESTER/DRYING BEDS

SECONDARY CLARIFIER

ACCELERATOR

POST AERATION

Cl₂ CONTACT

DISCHARGE

RECIRCULATE TO AERATION BASIN

SAND DRYING BEDS

AEROBIC DIGESTER

FIGURE 1 ORIGINAL PROCESS FLOW DIAGRAM
Table 2. Original Design Criteria

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow, mgd</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average flow, gpm</td>
<td>1,890</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum flow, gpm</td>
<td>3,850</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid Mix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume, gal.</td>
<td>9,800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRT, min.</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixer, Hp</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow Mixer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume, gal.</td>
<td>63,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRT, min.</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixer, Hp</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Clarifier</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter, ft.</td>
<td>110</td>
<td>13.5</td>
<td>280</td>
<td>580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overflow Rate, Avg. gpd/ft$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overflow Rate, max. gpd/ft$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aeration Basin</td>
<td></td>
<td>1.5-2.0 mgd</td>
<td>18-24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRT, hrs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerator Type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerator Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary Clarifier</td>
<td></td>
<td>70</td>
<td>13.5</td>
<td>570</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overflow Rate, Avg. gpd/ft$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accelerator</td>
<td></td>
<td>53</td>
<td>13.5</td>
<td>1,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diameter, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, ft.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overflow Rate, avg. gpd/ft$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preaeration</td>
<td></td>
<td>54,000</td>
<td>5</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume, gal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horsepower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HRT, min.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Original Design Criteria (Cont'd)

<table>
<thead>
<tr>
<th>Aerobic Digester</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>2</td>
</tr>
<tr>
<td>Volume, ea. mg.</td>
<td>0.5</td>
</tr>
<tr>
<td>Aeration, Hp. ea.</td>
<td>50</td>
</tr>
<tr>
<td>Depth, ft.</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drying Beds</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Area, ft²</td>
<td>3,080</td>
</tr>
</tbody>
</table>
Use of high pressure nozzles for cleanup and wash down

Replacement of many hand valves with automatic shutoff valves

Other water reduction methods could include:

- Makeup of scalders with chiller overflow. Some tradeoff in water savings versus increased heating costs must be made.
- Dry cleanup to the greatest extent possible
- More efficient equipment such as the final bird wash
- Modify giblet processing equipment to allow cleaning in place (CIP)\(^3\)
- Dry evisceration and offal handling
- Reuse of final bird wash to giblet flumes

As a result of these actions, the plant was able to reduce flow quickly to around nine gallons/bird. Increased attention to water use and upgrading of equipment over the last few years has resulted in a current water use of less than seven gallons per bird.

Reduction of flow was accompanied by a proportionate decrease in BOD and TSS loading to the system on a mass loading basis. This is typically the case in poultry processing where reduced water usage also reduces mass loadings, especially where water reduction is based on offal and cleanup sources.

This facility’s approach had elements typical of any successful water reduction program. Water use became a management issue. In many instances a person’s major responsibility may need to be water use and management to achieve low water use. The plant also monitored and studied areas of water use so they were aware of usage patterns at their plant. Use of outside help to sample and measure flows is often useful in obtaining a water and constituent to form the basis for action. Finally, water use must be made an issue to all employees to effect long-term reduced water consumption.

To demonstrate what others have done in the area of waste reduction, this plant is today in the 50-60 lb BOD per 1,000 birds processed and a water use of 7-8 gal/bird. Others have reported BODs in the 30 lb per 1,000 birds and water use in the 5-7 gal/bird range. These plants often report significant swings in waste loads based purely on how the equipment is operated. Rinse flow settings, overflows, bird wash, and cleanup all have some human element in them, and the potential to increase or decrease waste loads is often dependent on personnel’s approach.

Waste load reduction was also achieved by improved blood recovery. Common practice now is to stun the birds electrically to reduce splashing of blood. Containing the blood in troughs or curved areas is essential. Increased bleed time to maximize recovery is also essential to control BOD loads from blood. Determination of optimum bleed time is simple to figure: and should be based on the typical size of birds processed. Increasing the troughs for catching the blood can usually be accommodated as a simple modification.

Other areas in which flow and waste loads can be reduced include dry cleanup, especially around the evisceration area. This and other plants use copious quantities of water to clean floors and equipment. As noted in the earlier table, the BOD load from cleanup may be 20 percent of the total BOD load. The receiving area is one area to effect dry cleanup before applying water. Since most of the cleanup occurs after the processing day (usually in the late night or early morning hours), management changes may be necessary to monitor water use and cleanup procedures. This is an area where there is a potential conflict between environmental concerns and the USDA requirements for hygiene. No compromise is allowed for the final
plant cleanliness before beginning the next day's processing. However, there are ways to achieve the same cleanliness at reduced water flows through dry cleaning. The cleaning staff is often the lowest pay-scale staff and has no incentive to sweep or dry clean. Management must make this an emphasis, provide proper supervision, and monitor water use. Equipment changes that allow easier cleaning or cleaning in place (CIP) may also result in lower water use and reduced waste loads.

It is interesting to note here the trends in flows and waste load from poultry processing over the last 25 years. Articles published in the early 1960s indicated BOD loads of around 24 lb per 1,000 birds. At that time, offal flow-away systems were not a common practice in many plants. Production was less automated and much of the viscera was pushed away into barrels. Water had little contact with blood, food in various states of digestion, and other organic matter. Plants that had offal flow-away systems had BOD loads in the 35-50 lb per 1,000 birds. The study also found that the BOD load was dependent on the size of the bird being processed so that larger birds produced more BOD per bird even on a per pound of bird basis. Automation in the industry led to different processing equipment and methods and actually increased the BOD loads since many plants went to offal flow-away systems.

Other studies done in the early sixties reported water use as high as 20 gal/bird, but easily reduced to 10 gal/bird when the effort was made. Therefore, this case study plant had BOD loads higher than many plants had ten years previous, probably as a result of bird size and production practices including automation. To further reduce waste loads below 40 lb per 1,000 birds and flows below 6-7 gallons per bird, dry offal handling would need to be implemented.

There are many other possibilities for reduction of water through reuse. The Denver Water Reuse Plant treats municipal sewage to drinking water quality using tertiary treatment, ion exchange, reverse osmosis, and UV-ozone for disinfection. The incentives for this degree of reuse do not yet exist in the industry, but certain aspects may already have applications. Filtration of prechiller water using diatomaceous earth (DE) and UV irradiation has been demonstrated. This treatment resulted in a water reduction of 21 million gallons per year and a COD load of 179,000 lb/yr at a plant the same size as our case study plans.

**OPERATIONS MODIFICATIONS**

Reduction in solids wasting from the secondary system was recommended to increase active biomass in the aeration basin. The plant was put on a program of monitoring solids to get a better understanding of sludge wasting.

The results of the reduced water usage and solids wasting were effective in improving plant performance. The lower F:M ratio from having a higher biomass coupled with increased clarifier residence times resulted in lower effluent BOD concentrations. The mass-based limits compliance for BOD was greatly improved. In addition, savings on chemical costs at both the waste treatment facility and the water plant were realized.

**SOLIDS HANDLING**

Solids handling is an area where waste minimization and by-product recovery have been practiced for many years. Typically, feathers and offal are screened and rendered. Primary sludges usually DAF float, are often combined with offal for rendering. Renderers do not like taking watery sludges because of the energy required to evaporate the water, but they usually take the material because of its relatively low volume compared to the offal and feathers.

Several modifications recently have been implemented for improved solids handling. Secondary screening using an 0.02-inch rotary screen offers a significant improvement in recovery of material. These screens are externally fed and solid matter is “doctored” off in a relatively dry form. Although these screens do not reduce the amount of waste that is present in the DAF or primary effluent, it does remove the material in a more renderable manner. Other forms of primary treatment could include protein recovery in a process similar to AMINODAN that coagulates soluble protein to increase recovery of a DAF system.
CASE STUDY ISSUES

Alum solids from the primary clarifier continued to pose a problem. Originally, primary and secondary sludges were combined and digested before being placed on sand drying beds. The sludge was gelatinous and would not dry. We recommended that waste-activated sludge be segregated from the primary sludge before digestion. This practice at least allowed for the secondary sludge to be dried on the sand beds.

A vibrating inclined screen was purchased to assist in thickening the primary sludge. This was only marginally effective but did somewhat reduce the volume of sludge. The owner had begun to haul the sludge to his farm land for land disposal. The haul distance of approximately 40 miles round trip resulted in high disposal costs. Difficulties in getting required permits for land application of sludge led to the search for a permanent solution.

POTENTIAL SOLUTIONS

INSTALL A SKIMMER

Bench scale tests were done to evaluate the efficacy of settling without the use of chemicals. If no chemicals were used to aid settling, the sludge could be handled by a renderer.

The existing primary system was extremely efficient for TSS removal reducing the influent solids from 400-600 mg/l to below 100 mg/l, well over 85 percent removal. Similar oil and grease removals were seen. In the bench-scale settling tests, similar removals of TSS and grease were even without the use of alum and polymer. However, the grease accumulated at the surface, necessitating a surface skimmer on the primary clarifier.

Advantages of the skimmer were reduced chemical costs, no additional area requirements, and minimal capital equipment costs. Disadvantages included the difficulty of retrofitting the clarifier while keeping the processing plant in operation and some mechanical difficulties in supporting the skimmer to the rake and feed well.

MECHANICAL DEWATERING

Another option was to install a mechanical dewatering device, such as a belt press. Advantages included minimal changes to the existing operation and considerable sludge volume reduction. Disadvantages included additional chemical costs, high capital costs, and operating requirements, including labor and maintenance.

DISSOLVED AIR FLotation (DAF)

DAF without chemical addition would perform very similar to gravity settling. The advantages were elimination of chemicals, which would result in a renderable float and minimal interference with plant operation during installation. Disadvantages were high capital and operating costs, as well as the addition of more mechanical equipment.

ANAEROBIC LAGOON

Addition of an anaerobic lagoon to replace the primary clarifier system was evaluated. Advantages included low operation costs, elimination of sludge handling and chemical costs, and high treatment efficiency. Disadvantages included land requirements, odor potential, and elimination of a proven effective primary treatment step with one more susceptible to environmental influences.
**SELECTED OPTION**

**RATIONALE**

The anaerobic lagoon was selected as the desired alternative based on costs and ease of operation. The owner had his own construction forces and could construct lagoon facilities for much less cost than he could purchase mechanical equipment.

**DESIGN BASIS**

The anaerobic lagoon was designed based on the following conditions:

<table>
<thead>
<tr>
<th>Production Flow, mgd</th>
<th>200,000 birds/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅, mg/l</td>
<td>1.6</td>
</tr>
<tr>
<td>TSS, mg/l</td>
<td>740 average</td>
</tr>
<tr>
<td></td>
<td>940 (80 Percenule)</td>
</tr>
<tr>
<td></td>
<td>500 average</td>
</tr>
<tr>
<td></td>
<td>635 (80 Percenule)</td>
</tr>
</tbody>
</table>

This gave a daily BOD design load of 12,500 lb/yr.

Most anaerobic lagoons are designed based on volumetric BOD loading. Typical ponds in Alabama are designed in the 3-5 lb BOD₅/1000 ft³ range. A plant in Mississippi was loaded at 18 lb BOD₅/1000 ft³ and achieved 80% BOD removal efficiency.

Volumetric BOD loadings for meat packing wastes are typically from 8-15 lb BOD₅/1000 ft³.

The other design factor is detention time. Several literature sources recommend a minimum winter retention time of five days.

Design criteria selected were as follows:

<table>
<thead>
<tr>
<th>BOD load</th>
<th>12,500 lb/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design load</td>
<td>10.5 lb BOD₅/1000 ft³ for 5-day week</td>
</tr>
<tr>
<td></td>
<td>7.4 lb BOD₅/1000 ft³ for 7-day week</td>
</tr>
<tr>
<td>Volume</td>
<td>1,200,000 ft³ = 8,976,000 gal</td>
</tr>
<tr>
<td>Detention Time</td>
<td>5.6 days based on 5-day week</td>
</tr>
<tr>
<td></td>
<td>7.8 days based on 7-day week</td>
</tr>
<tr>
<td>Depth</td>
<td>15'</td>
</tr>
<tr>
<td>Freeboard</td>
<td>4'</td>
</tr>
<tr>
<td>Surface Area</td>
<td>225 acres</td>
</tr>
<tr>
<td>Side slopes</td>
<td>2:1</td>
</tr>
</tbody>
</table>

The size calculations were based on the following:

1. Loading consistent with case histories.
2. Detention time adequate for winter treatment.
3. Area/depth combination to prevent excessive heat loss and keep winter temperatures at 17°-20° to enable methane generation to occur.

**PERFORMANCE**

The anaerobic lagoon has given excellent performance for five years. Results from the first several months of operation are summarized in Table 3. Since that time, results have been more in line with the last three months in Table 3. Winter BODs will occasionally increase to about 200 mg/l for the coldest month. Early performance was erratic until the grease layer formed. This layer is now thick and stable and tends to moderate temperature resulting in rather stable performance. The process flow train currently in use is shown in Figure 2.
chemical feed facilities and primary clarifiers are no longer in use. As a result the plant has
saved over $15,000 per year in chemical costs alone. as well as eliminating sludge handling
problems.

Table 3. Anaerobic Lagoon Performance - BOD and TSS

<table>
<thead>
<tr>
<th>Month of Operation</th>
<th>Influent BOD mg/l</th>
<th>Influent TSS mg/l</th>
<th>Effluent BOD mg/l</th>
<th>Effluent TSS mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>680</td>
<td>370</td>
<td>360</td>
<td>130</td>
</tr>
<tr>
<td>4</td>
<td>960</td>
<td>680</td>
<td>230</td>
<td>110</td>
</tr>
<tr>
<td>5</td>
<td>865</td>
<td>140</td>
<td>220</td>
<td>160</td>
</tr>
<tr>
<td>6</td>
<td>780</td>
<td>20</td>
<td>340</td>
<td>160</td>
</tr>
<tr>
<td>7</td>
<td>1,220</td>
<td>780</td>
<td>75</td>
<td>80</td>
</tr>
<tr>
<td>8</td>
<td>1,380</td>
<td>370</td>
<td>115</td>
<td>40</td>
</tr>
<tr>
<td>9</td>
<td>920</td>
<td>264</td>
<td>108</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>960</td>
<td>208</td>
<td>120</td>
<td>50</td>
</tr>
</tbody>
</table>

In summary the anaerobic lagoon option is a cost-effective way to replace mechanical
primary treatment and significantly reduce BOD and TSS loads on downstream processes or
POTWs. The solution is a form of waste minimization because a significant amount of material
in the plant discharge is ultimately degraded- Some fraction of the solids remains, however, for
future handling through pond cleaning or closure. Impacts on groundwater are of much greater
concern now than when this and many other lagoons were constructed. Costs to design and
construct to prevent groundwater contamination along with monitoring costs will make this
option less attractive in the future.

Other options now exist that were not considered in the late 70’s when the anaerobic
lagoon was implemented. Several plants that I am aware of have significantly improved primary
treatment by adding polymers to the DAF feed In contrast to using alum as a coagulant. use
of FDA approved polymers allows DAF float to be rendered Effluent BODs of 150-200 mg/l
have been observed at plants using a two polymer system TSS reductions below 150 mg/l
were also produced This system probably offers the most immediate reduction in waste loads
that can be achieved, since little capital equipment is required and the float can continue to be
handled by a renderer.

AMMONIA REMOVAL REQUIREMENT

Water quality parameters such as ammonia may need consideration in a waste
minimization program. Impacts of high ammonia levels on treatment requirements are
illustrated in the case study.

PROBLEM DESCRIPTION

Approximately two years after startup of the anaerobic lagoon, the plant’s NPDES
permit was renewed. An ammonia limit of approximately 170 lb/day was based on water quality
standards proposed by the regulatory agency. On behalf of the industry, CH2M HILL
approached the agency for a seasonal permit for both BOD and ammonia to account for lower
reaction rates and higher stream dissolved oxygen during cooler weather. A seasonal
permit allowing an average and maximum 170 lb/day ammonia nitrogen for May
through December was granted. For January through April ammonia limits were approximately
230 lb/day average and 340 lb/day maximum. A slightly higher BOD was allowed in November
and December.

At the time of the proposed new permit, the plant mass ammonia discharge was in
excess of the proposed permit limits, averaging over 250 lb/day and often exceeding 300 lb/day.
The implementation date of the permit was approximately two years off because of the
upgrading of a municipal plant another major discharger to the stream. This allowed time to
evaluate plant performances and options for compliance.
AMMONIA REMOVAL BACKGROUND

Ammonia is removed in biological treatment by nitrifying bacteria in the presence of oxygen. The general reaction is:

$$\text{NH}_4^+ + 20_2 \text{Nitrifiers} \rightarrow \text{NO}_3^- + 2\text{H}^+ \text{H}_2\text{O}$$

In this biochemical reaction 457 pounds of oxygen are required per pound of ammonia removed. Alkalinity as calcium carbonate is also destroyed at the rate of about 7 pounds per pound of ammonia removed. The alkalinity is required for two reasons. First, the chemical reaction produces an acid which destroys alkalinity. Second, nitrifying bacteria need inorganic carbon (carbonate) for cell growth. Without carbonate alkalinity these organisms cannot reproduce, resulting in insufficient numbers of organisms to achieve adequate ammonia removal. Furthermore, the organisms that remove the ammonia are sensitive to pH and temperature. An optimum pH of seven to eight is generally required.

Ammonia removal rate is related to temperature by the Arrhenius relationship. A decrease of 10°C generally reduces the ammonia removal rate by around 50 percent.

Ammonia removal is also dependent on having an adequate concentration of nitrifying organisms in the activated sludge. A minimum sludge age (solids retention time) is required to allow an adequate concentration of the slower growing nitrifying bacteria in the mixed liquor. Operation below this minimum sludge age results in washout of nitrifiers, and ammonia removal virtually ceases. The required minimum sludge age is a function of temperature and ranges from around six days at 20°C to over 20 days at 10°C.

BENCH-SCALE STUDIES

The anaerobic lagoon effluent had insufficient alkalinity to allow complete ammonia removal. Influent alkalinitities around 300 mg/l would allow removal of around 40 mg of ammonia. With influent ammonia levels of 60-70 mg/l, a residual ammonia of around 25 mg/l would represent approximately 230 lb per day. Actual field ammonia removal data correspond to this value.

A cursory bench-scale test was initiated to assess whether alkalinity addition alone was sufficient to bring the system into compliance with the upcoming permit and to rule out any toxic substance that could be inhibiting nitrification. The bench-scale study was less expensive than adding alkalinity in the field over a long period. The study also allowed evaluation of nitrification at colder temperatures.

Two and one half liter lab reactor units were operated similar to the field system. Alkalinity was added as sodium carbonate. One unit was operated at 20°C and one at 8-12°C.

The 20°C unit exhibited excellent ammonia removal when sufficient alkalinity was added and showed that there was basically no problem meeting the summer ammonia limit. Operation at cold temperatures was quite temperature dependent. At 10-12°C ammonia removal was adequate. However, at temperatures below 10°C effluent ammonia levels rose to over 20 mg/l which would be marginal for compliance at one mgd flow.

FIELD RESULTS

The ammonia permit took effect in midsummer. Addition of alkalinity as lime effected immediate removal of ammonia to below permit levels. In an effort to reduce operating costs alkalinity was added only to a level required for compliance. This resulted in an extremely low pH in the aeration basin (5.5-5.5) since all the alkalinity was consumed by the nitrifying organisms. It was evident that the nitrifiers will not “stop” and that sufficient alkalinity must be added to keep the aeration basin pH above six.
Winter 1985 was the first cold period for which the plant had to achieve nitrification. Extreme cold temperatures in mid-December caused nitrification to cease. The high speed aerators had a cooling effect of over 10°C, resulting in aeration basin temperatures below 4°C. Ammonia levels averaged 230 lb/day for December with a maximum of 400 lb/day.

January 1986 results were similar. By February, the aeration basin had warmed a few degrees and the system was back in compliance.

Figure 3 shows the effects of temperature on effluent ammonia from December through early May. Ammonia removal in warm weather has been excellent averaging under 20 lb/day in the effluent as long as adequate lime is added. In fan as long as the pond temperature is above around 8°C (February through November), compliance is achieved.

It should be noted that the plant does not accurately account for solids wastage. However, with excellent BOD and TSS removal in the anaerobic lagoon and the relatively long hydraulic retention time in the aerobic system, sludge wastage is minimal, so the sludge age is well in excess of 25 days.

OPTIONS TO IMPROVE WINTER AMMONIA REMOVAL

With a relatively warm December 1986, ammonia compliance was achieved. However, in January 1987 average and maximum ammonia limits were exceeded. In 1985, we had felt that limiting alkalinity addition resulted in a system that was not nitrifying at full efficiency before the onset of cold weather. In late 1986, however, the system was removing virtually all ammonia before extremely cold weather in January. Thus, nitrifier population in the activated sludge was probably high, but cold temperatures lowered reaction rates below the level necessary to achieve compliance.

The surface aerators cool the aeration basin to a level very near ambient. It is our conclusion that the system will have a very difficult time consistently removing up to 40 mg/l ammonia at temperatures below 8°C.

One modification made in late 1986 was the addition of a high speed surface mixer in the aeration basin. Temperatures from the anaerobic lagoon are typically 15°C in the titer. Even with the long anaerobic retention time, the surface layer of grease insulates the basin, and it is only about 2-3°C less temperature drop. Since the surface aeration system is largely responsible for the temperature drop, use of a diffused air system would result in much less heat loss and probably eliminate compliance problems during the two coldest months.

There are several other approaches to achieving full compliance. The first and most desirable option is to modify the permit to more accurately reflect field temperatures and critical stream temperatures.

The ammonia limits are derived from water quality modeling. The current model uses low flows, approximately one cfs, from September, with the warmest expected stream temperature during the permit period. Current division of the permit has resulted in a stream model temperature relatively high for both the November-December and the January-April periods. Changing to a December to February period and using stream flows expected during the period, approximately 5 cfs, would allow over 500 lb ammonia for this critical period.

Actual stream measurements support the fact that dissolved oxygen is not a problem in extremely cold weather. Dissolved oxygen levels over 10 mg/l and temperatures of around 5°C were measured in the receiving stream in December 1985.

The agency is unwilling to be flexible on the permit issue. The permit should actually be dependent on stream temperature, not calendar months. However, using temperature as the trigger for permit levels increases monitoring and results in more difficulty for the agency both
to write the permit and to monitor compliance. An additional permit issue involving ammonia is toxicity, which was a new consideration in the latest permit.

**TOXICITY BASED PERMITS**

A new compliance issue is effluent toxicity. It is now required that discharges be permitted for toxicity in addition to their other regulated parameters, if toxicity is expected to be present in their effluent. Potentially toxic pollutants are identified and monitored as part of this requirement. The parameters of concern at this poultry processing facility are ammonia and chlorine. Although this section of the paper does not deal with waste minimization in the strictest sense, it does illustrate the complexity of the toxicity regulation and issues that must now be considered in an overall environmental compliance approach. Only with consideration of the permitting and compliance issues will it be possible to determine if waste minimization or further treatment will be required.

**APPROACHES**

There are two approaches to toxicity based permits: limits based on published toxic concentrations (found in the EPA “Gold Book”), and bioassay testing. A discussion of each follows.

In a permit based on the Gold Book numbers, numerical limits are calculated based on the IWC and toxic concentrations of each parameter of concern. This approach can only be used where the expected toxicants are known. The Gold Book contains tables of toxic concentrations for several parameters versus pH, hardness, and temperature of the receiving stream. The advantages of the numerical approach are that the limits are straightforward and the required monitoring is relatively inexpensive. The disadvantages are that the limits are arbitrary and inflexible. The Gold Book numbers often do not reflect actual stream toxicity, and are generally very conservative.

In a bioassay based permit compliance is based on the toxicity measured in bioassay testing. There are no toxicity-based numerical limits on various parameters. The advantages of the bioassay approach are that it represents actual stream conditions, and it is flexible. However, the required monitoring is expensive, and compliance is not always easy to assess. If the plant is in compliance, no action is taken. If the plant is not in compliance, it has to perform a toxicity reduction valuation (TRE), which is both difficult and expensive.

** ISSUES **

There are several issues to be resolved in negotiating a toxicity based permit. One issue is the values to assign to the variables needed to determine the permit limits. A related issue is how often to allow these values to vary. For bioassay-based permits the definition of compliance and the implications of noncompliance must be decided. A further issue is the existing toxicity of the receiving stream.

** VARIABLES **

The limits for either the numerical or the bioassay approach vary with the instream waste concentration (IWC). Consequently, care is necessary in selecting the numbers used to calculate it. IWC is calculated by dividing the plant’s effluent flow by the total flow in the receiving stream.

There are several candidates for the stream flow values: the IQ10, the 7Q10, and actual measured values. These are listed in order of decreasing conservatism. The IQ10 (the lowest one-day flow expected in a 10-year period) is sometimes desired by the regulator, but is excessively conservative. The plant would benefit from using measured flows, but this approach is difficult for the agency to enforce. A typical compromise is the 7Q10, the lowest weekly average flow expected in a 10-year period. However, the 7Q10 is often zero on small stream, requiring an effluent to be non-toxic at 100 percent strength.
The other number used in the IWC calculation the plant’s effluent flow, is less controversial. The choices are the design flow of the plant’s wastewater treatment facility, their maximum measured flow, their long-term average flow, or their monthly average flows.

Permit limits based on the Gold Book numbers also vary by the pH, hardness, and temperature in the receiving stream. These values vary considerably over time. The permit should also vary with these factors.

The amount of variation allowed is negotiable. Some states will allow permit based on daily variations in flow and temperature. On the other end of the scale, some permits may be written with only one set of values to be used the entire year. Monthly or seasonal variation is generally acceptable, however.

Another variable for the bioassay approach is the dilution water used. The test measures the survival and health of organisms living in 100 percent dilution water versus organisms living in plant effluent mixed with dilution water. The dilution water may either be wafer from the receiving stream taken from upstream of the plant outfall or synthetic dilution water. The advantage of using receiving water is that it is more representative of the actual stream conditions. However, the receiving stream wafer cannot be used if it is toxic, and it often is. The advantage of using standard synthetic dilution water is that it is generated in the lab, eliminating any potential sampling error.

**COMPLIANCE**

An issue of the bioassay based permit is the definition of compliance. There are a couple of different measures of toxicity: the no observable effect concentration (NOEC), and the chronic value (ChV). Compliance can be defined as either of these value being greater than the IWC. Alternatively, compliance can be defined as no degradation of receiving water quality, which could have several interpretations.

NOEC and CHV are measured as follows. When a definitive bioassay test is run, a series of concentrations is tested. The NOEC is the highest concentration tested where there was no statistically significant difference between the survival and measured health (generally reproduction or growth) of the control organisms and the organisms grown in that concentration of plant effluent. The lowest observable effect concentration (LOEC) is the lowest concentration at which there was a statistically significant difference. The ChV is the geometric average of these two numbers.

A further compliance question is what bioassay test is performed. The variables are the duration of the test (48- or 96-hour acute tests, or 7-day chronic tests), whether a screening (one concentration only) or definitive test is run, and the species used in the test. Typically chronic tests run on ceriodyphnia and fathead minnows are selected where the IWC is greater than 1 percent. Definitive tests give more information, but are more expensive. Screening tests are typically performed at the IWC, if they are allowed. However, they only give a pass or fail answer. Typically it is advantageous to perform definitive tests at least in the beginning. Often one of the species can be dropped at some point if the other species has been shown always to be more sensitive.

The final monitoring issue is frequency. Since bioassay tests are so expensive, typically the most frequent monitoring required is once per month. Some plants are required to test on a quarterly or annual basis.

An issue related to the definition of compliance is the result of noncompliance. Because bioassay tests use organisms, they are not entirely repeatable. A failed bioassay may reflect a biological anomaly, a slight difference in effluent quality, or a chronic problem. Toxicity is not directly treatable, and it is often unclear what is causing the toxicity. A TRE involves considerable expense and difficulty, and should not be required on the basis of a single bioassay. Often increased monitoring can be performed before a TRE is required. Most of these issues must be considered on a case-by-case basis.
TOXICITY IN THE RECEIVING STREAM

The problem of toxicity in the receiving water is relatively common. If the water is already toxic, it is difficult to measure the effect of the plant effluent on the stream. It is normally acceptable to show that an effluent has no adverse effect on the receiving stream quality. The receiving stream may be toxic due to point sources upstream of the plant or even to non-point sources or naturally occurring pollutants. Furthermore, many municipal permits do not yet consider toxicity.

IMPLEMENTATION AND RESULTS

The approach we took to resolve these permit issues was as follows. First, we performed pre-permit bioassay monitoring to evaluate the plant’s toxicity status. We also calculated the numerical limits based on the Gold Book values and reviewed historical data to estimate whether these limits could be met.

To calculate the Gold Book numbers, the flows, pH, hardness, and temperature to be used were estimated from historical data on the receiving stream. We discussed these assumptions with the regulators so that the assumptions used in the permit were conservative but reasonable.

Finally, we reviewed the wording of the permit to allow the plant as much flexibility as possible. It was also necessary to modify some of the wording to avoid ambiguity.

We recognized that the same issues we faced in complying with ammonia Limits applied to the toxicity limits. Although ammonia removal declines in the winter month, the stream is less sensitive to ammonia and the dilution in the stream increases dramatically. Monthly 7Q10 values range from 40 cfs in March to 0.8 cfs in October, a 50-fold difference. Moreover, according to the Gold Book ammonia is less toxic at lower temperatures. We found that the ammonia limit calculated from the Gold Book for the winter season (January through April) were higher than the existing ammonia permit limit for that period. The toxicity based limits were significantly lower than the existing ammonia limits for the rest of the year.

Chlorine was only considered during the winter, as ammonia controlled. The calculated limits for chlorine in the winter were also higher than the existing permit limits.

In this case, the agency allowed up to four seasons. chosen by the plant ITWC is based on the lowest monthly 7Q10 for the months in the season, and temperature is based on the highest monthly average temperature in the season. We found that the plant was unable to meet the Gold Book ammonia Limits for three of these seasons. We negotiated a permit which allowed numerical limits for one season (winter) and monthly bioassays for the remainder of the year. So far the plant has been able to comply with these limits without making process changes.

CONCLUSIONS

In Summary, much of the water quality related problems associated with the case study revolved around a poorly designed primary system. Anaerobic treatment is a cost-effective method to reduce BOD, suspended solids and oil and grease prior to secondary treatment. However, in the face of stringent water quality problems such as ammonia and its related toxicity chemically assisted DAF could be considered a superior process. Although DAF will have increased capital and operating costs the ammonia load on the biological process will be significantly lower. Based on current cost renderers are charging for ‘wet’ floats or primary sludges it is still not cost-effective for the processor to dewater onsite. However, this trend will probably change and DAF may have to include dewatering costs, which will add even more to the capital and operating costs. However, with the stringent water quality limits, it will be necessary to evaluate this degree of waste minimization compared to operating a biological system to give very high degrees of ammonia removal year round.
PREPARED FOOD CASE STUDY

We have also done wastewater treatment and in-plant evaluation at a producer of cooked chicken products. The plant cooks whole chickens and makes a variety of canned products including soup, canned boned chicken, canned whole chicken and dumplings.

IN-PLANT WASTE REDUCTION

Plant production and cleanup procedures were observed to identify potential areas where water consumption and water generated could be reduced.

COOKING ROOM

The largest wastewater volume is generated in the cooking room by vats used to cool the cooked chicken. The four cooling vats operate at a continuous flow represents approximately 50 percent of the total wastewater flow and contain approximately 8 percent of the plant BOD load. Using this cooling water as makeup water for cookers is a potential alternative to flow reduction.

DOUGH ROOM

The dough room, or dumpling preparation area, contributes an estimated 17 percent of the wastewater volume and over 18 percent of the plant BOD load.

BOD sources include blancher losses and wafer used to cool and transport the dumplings from the blancher to canning areas. Blancher losses include drips and overflow from the top of the blancher as well as leaks along bottom seams and fittings on the end of the rank.

Containment of blancher overflows and blancher contents for disposal would reduce both BOD and solids loading on the WWTF. Blancher contents possibly could be stored and reused. Disposal offsite as a liquid or evaporation to meet moisture limits for rendering are also alternatives.

Flour losses and dumplings lost in the flour were as deep as 6 inches, and covered a large area. When this flour pile becomes wet it contributes BOD and solids loadings to the WWTF. The wet flour is also more difficult to clean up than dry flour. Hourly dry cleanup of flour and dumplings on the dough room floor was recommended to reduce these losses. This practice should reduce the BOD and solids discharged during production shifts as well as reduce the effort and volume of water required during the cleanup shift. Potential cleanup methods include shoveling the flour and dough into containers or using a wet-dry vacuum.

CANNING LINES

Sealed cans are washed before pressure canning in the retorts. Reducing the water used by can washers may be possible. Flows of 6 gpm and 8 gpm, respectively, were measured from two canning line.

Use of a high pressure, high temperature can washes may achieve the same cleanliness at a lower flow rate. Reductions in can wash flows would primarily reduce total wastewater flows and not reduce BOD and solids loads, and could result in lower pumping costs and lower chemical usage in the WWTF.

BROTH LOSSES

Broth is lost during can filling and sealing operations as well as during broth preparation, distribution, and storage. Broth is lost because it is pumped continuously even when there is not a can under the filler line. Automation to make the broth fill only when a can is in place would reduce the BOD load.

BONING ROOM
Removing meat from cooked chickens on the boning line produces an intermittent wastewater flow estimate at 2 gpm. A more significant boning room source is the water released when the carts of cooked chickens are emptied onto the boning line table. This liquid is about 6 percent of the plant’s BOD load on diluted chicken broth from the cookers. Containing this liquid and evaluating potential use in other plant operations is recommended.

As in the processing plant cleanup is a major use of water. During the night cleanup shift, two hoses sprayed continuously to wash the hook conveyor. This type of continuous washing contributes a large quantity of relatively clean water and should be maximized.

**SUMMARY**

In summary waste minimization has been practiced in the poultry processing industry for a long time. With advanced water treatment methods there are other reductions in flow and waste loads that can be made. The paper has presented methods to reduce flow and load, most of which are common sense. Research conducted in conjunction with the USDA is needed to identify further processing changes that can be implemented and still meet product safety and consumer needs. Changes in water quality regulations that require even higher degrees of treatment for NPDES discharges and higher user charges for pretreaters will keep the pressure on the industry and provide the incentive to continue to address all aspects of waste treatment including waste minimization.
REFERENCES


