Anaerobic-Aerobic Pretreatment of a Dairy Waste
A Case History

A. A. Cocci, B. F. Burke, R. C. Landine and D. L. Blickenstaff

Abstract

In 1987, High’s Dairies Inc. undertook a waste characterization and pilot study to assess anaerobic treatability of the wash water and whey from its Frederick, MD, operations using the ADI-BVF® low-rate reactor. The data from the study was to be used to establish criteria for design of a full-scale treatment system.

The pilot reactor was operated at 32°C and an average organic loading of 1.17 kg COD/m³.d; it achieved average COD, BOD, SS and FOG removals of 90.5, 94.9, 71.0 and 74.2 percent, respectively, under steady-state conditions. The biogas quality averaged approximately 65 percent CH₄, 0.3 percent H₂S and 35 percent CO₂.

On the basis of the pilot study and a comparative analysis of alternative anaerobic systems with aerobic polishing, it was determined that the low-rate BVF™ reactor, followed by an extended aeration plant, would be the most suitable and cost-effective system to meet the treatment requirements. Of significant importance in the economic analysis for the low-rate reactor was its ability to digest high levels of raw influent SS, FOG and waste aerobic solids from aerobic polishing and the fact that no pretreatment was needed.

In the fall of 1988, High’s began construction of a 2.5 MG BVF reactor followed by an activated sludge plant. Details of the system are provided in the text.

The BVF reactor began start-up in April 1989 and was through start-up in July 1989. Since July, the anaerobic reactor has typically achieved BOD/COD/SS removals of approximately 97, 95 and 85 percent, respectively. The overall system removals have been typically 99, 99 and 95 percent COD, BOD and SS, respectively.

All the biogas from the reactor is collected, with the majority of the gas burned in a triple-fuel boiler for the production of process steam; excess biogas is flared. The biogas supplies from 40 to 80 percent of the fuel requirements for process steam, depending on the season. Details of the biogas/boiler system are provided in the text.

Keywords
Dairy wastewater pretreatment, whey disposal, ADI-BVF®, low-rate anaerobic reactor, anaerobic-aerobic pretreatment, extended-aeration activated sludge, biogas.

Introduction

High’s Dairy of Frederick, Maryland, manufactures a variety of dairy products (cottage cheese, sour cream, yogurt, ice cream mix, etc.) for domestic markets. Prior to 1989, process wastewater, whey, clean-up, and sanitary wastewater were treated on-site in an activated sludge system prior to discharge to the City sewer.

Wastewater from High’s existing treatment facilities was contributing significant pollution loads to the municipal sewage treatment plant. The City, under pressure from the Maryland EPA to reduce its pollution discharges, asked High’s to develop a plan to reduce its pollution load to the City sewer. The initial plan involved in-plant process modifications and the elimination of whey treatment in High’s existing treatment works. Whey was stored on-site and trucked to area farms at considerable cost to High’s.

In addition to the above plan, in 1987 ADI International Inc. was commissioned by High’s Dairy to carry out a pilot-scale anaerobic treatability study on the wastewater generated at its Frederick operation. The purpose of the pilot study was to investigate the anaerobic treatability of the wastewater, including whey, as well as to address concerns with operation and performance of the proposed low-rate anaerobic reactor. In addition to the pilot study, a wastewater flow and characterization study was also undertaken.

On the basis of the successful pilot results and together with the results of the flow and characterization study, it was concluded that ADI-BVF anaerobic pretreatment followed by aerobic polishing would satisfy discharge requirements.

Various anaerobic systems were considered, and the low-rate ADI-BVF system with biogas recovery and utilization, followed by an extended-aeration system, was judged by High’s to best meet their treatment plant needs. Subsequently, High’s signed a contract to have the above facility designed and constructed.

The following sections highlight the results of the pilot study, present operating data and details of the full-scale treatment system, including biogas handling.

Pilot Study

Objectives

The primary objectives of the pilot study were to:
1. Verify anaerobic treatability of the raw process wastewater including whey.
2. Verify proposed design criteria for the full-scale system.
3. Evaluate the system performance in terms of BOD/COD/SS/FOG removal.
4. Determine chemical requirements for nutrients and pH control.

**Apparatus**

The system consisted of a feed storage container and mixer; timer-controlled variable-speed pumps to feed the reactor and recirculate sludge; a 7.0-liter ADI-BVF reactor with heating tape for temperature control; biogas flow meter; and biogas collection and analysis equipment (see Figure 1).

**Operation**

The reactor was seeded with municipal anaerobic sludge and fed daily (7 days/week) with a composite sample consisting of process water and whey. The reactor was operated at a hydraulic retention time of 13 days, a 1:1 sludge recycle ratio and a temperature of 32°C.

The pilot study consisted of two phases: Phase 1 (day 1-56) was start-up, where the feed strength was gradually increased to full strength; Phase 2 (day 57-113) involved steady-state operations in terms of feed strength (i.e., 100 percent full strength).

Chemical additions for both nutrient and pH control were adjusted as required throughout the term of the study. Table I presents the sampling and testing schedule used throughout the study; Table II is a summary of the average characteristics of the raw wastewater used as influent.

**Pilot Study Discussion**

The overall results indicated that the low-rate BVF reactor was well-suited for treating the process wastewater including whey generated at High’s. Average COD, BOD, SS and FOG removals during steady-state operations (Phase 2), were 90.5, 94.9, 71.0 and 74.2 percent, respectively. The average loading rate and temperature for the same period was 1.17 kg COD/m³.d and 32°C, respectively.

Overall, both COD and BOD removal efficiencies exceeded 90 percent after an initial two-week acclimation period (approximately one HRT); SS removals during the same period were lower, averaging 71 percent.

**Table I. Sampling and Testing Schedule**

<table>
<thead>
<tr>
<th>Test</th>
<th>Reactor</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp.</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>pH</td>
<td>D (G)</td>
<td>D (G)</td>
</tr>
<tr>
<td>BOD</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>COD</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>SS</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>VSS</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>FOG</td>
<td>TW (G)</td>
<td>TW (G)</td>
</tr>
<tr>
<td>alk.</td>
<td>TW (G)</td>
<td>TW (G)</td>
</tr>
<tr>
<td>VA</td>
<td>TW (G)</td>
<td>TW (G)</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>TKN</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>TOT-P</td>
<td>W (C)</td>
<td>W (C)</td>
</tr>
<tr>
<td>CO₂+H₂S (CH₄ by difference)</td>
<td>W (G)</td>
<td>W (G)</td>
</tr>
</tbody>
</table>

Note: D = daily
W = weekly
TW = twice weekly
G = grab
C = composite (produced from daily grabs)

**Table II. Average Raw Wastewater Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD, mg/L</td>
<td>13 200</td>
<td>13 200</td>
</tr>
<tr>
<td>BOD, mg/L</td>
<td>8 975</td>
<td>8 975</td>
</tr>
<tr>
<td>SS, mg/L</td>
<td>1 100</td>
<td>1 100</td>
</tr>
<tr>
<td>VSS, mg/L</td>
<td>950</td>
<td>950</td>
</tr>
<tr>
<td>TKN, mg/L</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>NH₃-N, mg/L</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Total P, mg/L</td>
<td>139</td>
<td>139</td>
</tr>
<tr>
<td>FOG, mg/L</td>
<td>405</td>
<td>405</td>
</tr>
</tbody>
</table>

Sodium bicarbonate (NaHCO₃) was added to the reactor influent to increase the buffering capacity and alkalinity. Through days 1 to 47, NaHCO₃ addition was 2 g/L. Through days 48 to 113, NaHCO₃ addition was gradually reduced from 2 g/L to 0.25 g/L. It was felt that because of the high influent TKN no chemical for pH control would be needed in full-scale. The final effluent pH consistently stayed slightly above the neutral value—a desirable pH for stable operation.

During start-up, nitrogen and phosphorus supplements were added to the feed to ensure adequate nutrient availability for the anaerobic microorganisms. These nutrient supplements were subsequently eliminated as of day 43, as N and P testing indicated these nutrients were available in large excess.

Biogas analysis indicated that the average gas composition was approximately 65 percent CH₄, 35 percent CO₂, and 0.3 percent H₂S. The biogas was therefore of good quality and suitable as an alternative fuel.

**Full-Scale System**

**Design Data and Criteria**

Design data for the raw waste influent to the treatment system are as follows:

- **Average flow** = 681 m³/d (weekly average)
- **Peak flow** = 908 m³/d (daily peak)
- **COD** = 12 000 mg/L, 8 170 kg/d (weekly average)
- **BOD** = 18 000 mg/L, 16 340 kg/d (daily peak)
- **SS** = 400 mg/L, 300 kg/d (weekly average)
- **pH** = 4.12
- **Temperature** = 21°C
The final effluent limits are:

- **BOD** = 250 mg/L
- **SS** = 160 mg/L

The anaerobic-aerobic system consists of a 2.5 MG ADI-BVF reactor followed by a Davis Water and Waste Industries packaged, extended-aeration activated sludge system. The average COD loading, calculated on the basis of the average raw wastewater characteristics and a reactive volume of 2.5 MG, is 0.9 kg/m³.d in the BVF reactor. The HRT of the anaerobic reactor is 13.9 days. The projected BVF performance is 85 percent BOD removal.

The Davis extended-aeration plant is sized for an average HRT of 1.3 days and an F/M of 0.15.

**System Description**

Figure 2 is a process schematic of the wastewater treatment facilities. The wastewater treatment facility is a supply-and-install system by ADI International Inc. and Davis Water and Waste Industries, Inc. In addition to the wastewater treatability study and the wastewater flow and characterization study, the scope of supply included:

1. overall site plan of the total treatment system (ADI);
2. design, drawings and specifications for a pile-supported, reinforced concrete foundation for the BVF reactor and the aeration system (ADI);
3. design, drawings and specifications for anaerobic and biogas yard piping (ADI);
4. design of control building (ADI);
5. supply and installation of the heat exchanger, biogas handling equipment, internal equipment for the BVF reactor, floating membrane cover system, boiler, electrical and controls systems (ADI);
6. BVF reactor start-up, commissioning and training services including preparation of process operating manuals for process start-up and biogas utilization system (ADI);
7. extended-aeration activated sludge system (Davis);
8. raw waste pumping station (Davis);
9. whey pump and whey storage (Davis);
10. influent and effluent piping (Davis);
11. liquid flow measurement and sampling (Davis); and
12. WAS pumps and piping (Davis).

Construction of the wastewater treatment facility commenced in October 1988 and was completed in April 1989.

**Anaerobic Reactor**

The BVF reactor is a field-erected, welded steel tank 137 ft diam by 25 ft high. The reactor is covered by a floating, insulated, flexible geomembrane cover which is designed to maintain reactor temperature, collect biogas and prevent escape of odors.

Control of odor was a prime consideration because of complaints High's had received while operating the former treatment facilities. Cover material is arranged in folds designed to allow rainwater collection in controlled locations and subsequent removal from the cover. The cover also incorporates access hatches and sampling ports to allow easy access for inspection and monitoring.

The low-rate reactor is complete with all internals including influent/sludge recycle headers; submersible, low-speed mixer; sludge wasting system; and two gas/liquid/solids separators (GLSSs) to further aid in the control of solids leaving the reactor.

Anaerobic effluent passes out of the BVF reactor through the GLSSs. The effluent system is designed to minimize reactor short-circuiting, retain sludge and improve effluent quality. Anaerobic system effluent flows by gravity to the aerobic system for polishing. Final effluent from the treatment plant flows by gravity to the City sewer.

**Biogas Equipment**

Biogas is generated in the BVF reactor on a continuous basis and collects as it rises to the surface beneath the reactor cover. The cover is constructed to allow biogas to flow to the perimeter collection system. Biogas produced in the reactor is drawn off under vacuum by the PLC-controlled, variable-speed duplex blower system. The biogas blowers compress the biogas for delivery to the boiler and/or flare. Biogas is burned in a multi-fuel boiler to produce steam; excess biogas is flared. In addition to the blower system and new boiler (including boiler control system), the biogas handling facilities include moisture removal equipment (sediment trap and drip traps), safety equipment (ambient gas monitors, biogas analyzer), biogas monitoring equipment (pressure and temperature switches/gauges, flow meter) and other accessories to ensure safe delivery of the biogas to the boiler and/or flare.

The biogas blowers are driven by AC induction motors controlled by variable-frequency drives (VFDs) so that the rate of biogas removal is identical to the gas production rate. In automatic operation only one blower is used at a time; the alternate unit is designated as a standby unit. The duty and standby designations are changed daily (automatically by the PLC) to balance wear on the blowers, motors and drives.

In normal operation, the starting, stopping and speed control of the VFDs is performed by the PLC. The control panel also has a complete set of manual controls for operating each blower. A standby generator set is provided to supply emergency power. This power is limited to supplying the wastewater treatment plant PLC (which in turn supplies the flare control panel) and one of the blowers.

In addition to the wastewater treatment plant control system, a boiler control system is provided with the new 350 hp, high-pressure steam boiler. The boiler control system is...
designed to automatically burn as much biogas as is available while maintaining proper boiler control and steam production. The control system is devised to permit the simultaneous burning of biogas and natural gas or oil in the boiler.

The controls can be reduced to two basic systems: 1. burner management and flame safeguards and, 2. combustion controls. These systems have been implemented through a combination of a Fireye flame safeguard system and a PLC. All control functions except those of the flame safeguard system are executed by the PLC.

The burner management system utilizes a combination of the Fireye controller and the PLC. Ignition and post-combustion sequences are initiated by the Fireye. The Fireye control sequence is received by the PLC which responds by starting up and shutting down the burner in an orderly and safe manner.

Once the burner system has been started by the burner management system, air and fuel controls are transferred to the combustion control system. The combustion controls ensure that the correct quantities of air and fuel are being delivered to the burner system for a safe and efficient flame.

Aerobic System

The aerobic system is a packaged, extended-aeration, activated sludge system. The unit consists of an outer steel tank 51.5 ft diam by 24 ft high and an inner steel tank (clarifier) 32 ft diam by 20.5 ft high.

The aeration tank is located in the annular ring between the outer wall and the clarifier wall. Wastewater from the anaerobic reactor enters the aeration basin through a submerged distribution system. Mixed liquor leaves the aeration basin via a trough around the outer perimeter of the clarifier and enters the clarifier section through a pipe at the center.

In the clarifier, activated sludge settles to the bottom of the clarifier where it is scraped to a center collection sump. A sludge return system pumps sludge from the clarifier sump back to mix with the aeration tank influent. A waste sludge pump and piping system is used to waste aerobic sludge (WAS) to the BVF; WAS is only wasted to the BVF reactor. A surface skimmer is used to move floating material and scum to the scum collection box. The collected scum is returned to the aeration basin.

Final effluent flows through a flow box mounted on the side of the aeration tank. A V-notch weir, flowmeter and sampling system are provided for monitoring final effluent prior to discharge to the City sewer by gravity.

BVF Reactor Start-Up

The BVF reactor was initially filled with water from the City water supply system. The basin contents were then heated to 30°C using an in-line shell-and-tube heat exchanger. Approximately 40 m³ of whey were added to the reactor to provide an initial "food" source for the seed sludge. Sodium carbonate (Na₂CO₃) was added to the reactor contents to adjust the pH to 7 prior to seed sludge addition. Seed sludge was obtained from the Frederick municipal wastewater treatment plant anaerobic digesters. Approximately 1900 m³ of sludge (1-2 percent SS) were added to the reactor. The seed sludge was trucked to the site, screened (12 mm bar screen) and pumped to the BVF reactor. Once the BVF received the sludge, raw wastewater feeding began.

The start-up lasted approximately 16 weeks. During the first several weeks of operation, only plant process wastewater (whey excluded) was added to the reactor. Over the remainder of the start-up period whey was gradually introduced until all plant process water and whey was being treated in the reactor. Soda ash and lime were added manually and daily to the influent pumping station to maintain reactor pH of approximately 7; heating of the reactor was done to maintain a temperature of approximately 30°C.

Physical Control of Reactor and Aerobic System

Operation of the BVF reactor is a relatively simple and uncomplicated process. Under normal operating conditions a minimum of operating attention is required.

Plant process wastewater flows by gravity into a wet well for screening and grit removal and then into the raw waste influent pumping station. Whey from the plant flows to the whey storage tank where it is metered to the influent pumping station. The raw waste pumps deliver wastewater to the reactor automatically, via a float control system. The run time of the whey pump is controlled by the PLC. The anaerobic sludge recycle pump and low-speed mixer are automatically controlled by the PLC. The recycle rate and the amount of mixing is adjusted in the field to achieve maximum reactor performance.

In order to maintain the BVF reactor at 30°C (system is presently operating at 26°C), a heat exchanger is utilized. Reactor supernatant is pumped through the heat exchanger. In the heat exchanger, steam is used to raise the temperature of the supernatant. The heated supernatant is then pumped to the influent header where it mixes with raw wastewater and recycled sludge. The supernatant pump is controlled by the PLC; the temperature rise through the heat exchanger is manually controlled.

Anaerobic reactor effluent flows by gravity to the aeration basin and clarifier and then to the City sewer. During normal operations, the aerator blowers (2 @ 75 hp, one is standby) are controlled automatically by the PLC. All aerobic sludge is wasted to the BVF reactor for anaerobic digestion. In normal operation, the starting and stopping of the WAS pump is done by the PLC.

The wastewater treatment plant control system is composed of the following components:
1. Programmable Logic Controller (PLC).
2. Reactor Monitor (RM).
3. Operating Control Devices (OCD).

These components interact as follows:
1. The operating control devices (i.e., START/STOP, HAND/OFF/AUTO switches, push buttons and meters for operating the biogas blowers, mixer, pump, etc.) determine whether equipment is to be manually or automatically controlled.
2. The PLC determines when equipment should be operated in the automatic mode, monitors analog signals, and provides alarm detection and safety interlocking.
The RM monitors the PLC, giving the operator a visual display of the process, and allows the operator to modify operating parameters.

Although the system is highly automated, operation is simple and straightforward and, should the need arise, the entire system can be operated and controlled manually.

An operator was on duty 8 hours per day, 5 days per week; since the reactor has reached maturity (after approximately 12 months), the operator is now only needed for 4-6 hours per day. The operator’s daily routine includes analytical testing, daily sample collection, and minor maintenance.

### Performance

Monthly operating data is given in Table III, and a monthly performance summary is presented in Table IV. Since start-up was completed (August 1989), the COD, BOD, and SS removals in the BVF reactor have averaged approximately 95, 97, and 85 percent, respectively. Overall average removal of COD, BOD, and SS have typically been 99, 99 and 95 percent, respectively. The average BVF reactor unit loading has been approximately 0.6 kg/m³.d, COD basis. Both the flow and the BOD/COD concentrations are below design values at the time of writing. However, the SS concentrations in the raw wastewater are running 4-5 times above design values.

### TABLE III. High’s Dairy Waste Treatment System - Monthly Data Summary

<table>
<thead>
<tr>
<th>Month</th>
<th>Flow m³/d</th>
<th>COD (mg/L)</th>
<th>BOD (mg/L)</th>
<th>SS (mg/L)</th>
<th>COD Loading (g/m².d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>681 12 000 3 000</td>
<td>4 806 720 210</td>
<td>440</td>
<td>160</td>
<td></td>
</tr>
<tr>
<td>Apr. 89</td>
<td>304 19 647 1 260 367</td>
<td>1 214 245 98</td>
<td>63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 90</td>
<td>530 7 438 650 246</td>
<td>4 792 272 118</td>
<td>1 730 180 103</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>June 90</td>
<td>517 11 613 1 530 141</td>
<td>9 780 1 083 67</td>
<td>1 902 337 51</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>July 90</td>
<td>482 10 185 820 150</td>
<td>7 017 299 78</td>
<td>1 958 349 77</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Aug. 90</td>
<td>529 10 911 488 105</td>
<td>6 970 99 8</td>
<td>2 109 224 43</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Sept. 90</td>
<td>474 10 422 621 90</td>
<td>7 833 148 11</td>
<td>2 094 275 32</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>Oct. 90</td>
<td>445 12 900 530 71</td>
<td>7 950 115 8</td>
<td>2 112 315 24</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Nov. 90</td>
<td>401 14 693 504 92</td>
<td>7 735 54 12</td>
<td>1 761 234 48</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Dec. 90</td>
<td>360 14 858 503 220</td>
<td>3 778 52 63</td>
<td>1 410 371 33</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>Jan. 90</td>
<td>329 15 093 418 327</td>
<td>8 120 28 41</td>
<td>1 877 273 139</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>Feb. 90</td>
<td>365 14 539 361 335</td>
<td>7 817 49 112</td>
<td>2 047 215 67</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Mar. 90</td>
<td>348 15 065 330 229</td>
<td>8 644 37 43</td>
<td>2 029 187 65</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Apr. 90</td>
<td>360 14 270 206 199</td>
<td>6 367 33 42</td>
<td>2 163 67</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>May 90</td>
<td>302 12 906 305 247</td>
<td>1 707 37 70</td>
<td>2 140 177 62</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>June 90</td>
<td>356 11 605 439 270</td>
<td>6 012 81 55</td>
<td>1 969 322 75</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>410 13 076 596 205</td>
<td>7 206 173 56</td>
<td>1 910 260 73</td>
<td>0.55</td>
<td></td>
</tr>
</tbody>
</table>

The reactor pH is maintained at 6.7 or above; the total alkalinity normally ranges from 1600 to 1800 mg/L, and the volatile acids level is normally in the 400 to 500 mg/L range. Soda ash and lime were added manually at the influent pumping station for pH control; as of February 1990, no chemicals are being used to adjust pH. As well, no volatile acids level is normally in the 400 to 500 mg/L range.

percent methane. The volume of biogas used daily is a function of season (demand in the plant). In the summer months, biogas is displacing approximately 40 percent of the fuel required for process steam and 80 percent in the winter.

### Acknowledgements

A.A. Cocci, B.F. Barke, and R.C. Landine are employed by ADI International Inc., Salem, New Hampshire, and Fredericton, New Brunswick, Canada. D.L. Bickenstaff is employed by High Dairies Inc., Frederick, Maryland.

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