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PLUG FLOW DAIRY DIGESTER CONDITION AFTER 16 YEARS OF OPERATION

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ABSTRACT

Langerwerf Dairy is a 400 cow dairy in Durham, California with an RCM plug flow anaerobic digester that has been in operation continuously since 1982. By 1997 digester gas production had dropped by about 30% due to holes in the gas collection bag and loss of volume due to solids accumulation. This project disassembled the digester, removed accumulated floating crust and settled sludge, evaluated component condition, and replaced some components. The digester was refurbished and restarted at a cost of $50,000. 60 days after the restart electricity production was 50% higher than before the project began. Findings after 16 years of operation are: 1) floating crust averaged 4 feet thick; 2) settled sludge averaged 5.5 feet thick; 3) sludge and crust occupied 2/3 of the digester volume: 4) the digester only accumulated 1% of the solids that would be estimated using NRCS sludge accumulation volume calculations; 5) hypalon gas bag material degraded; 6) there was minor corrosion of digester concrete and steel; 7) digester service life estimates can be increased from 20 years to 30 years; 8) total system operation and maintenance cost is about 4% of total capital costs annually; and 9) digester operation and maintenance cost is 2.9% of digester capital costs annually. Major project costs were removing crust and sludge, new greenhouse parts, and buying and installing a new gas bag with attachment hardware. The 1981 project cost was $200,000 while the gross value of digester products to date has been $698,000. Operation and maintenance costs to date have been $160,000. The dairy received matching grant assistance from the Western Regional Biomass Energy Program (WRBEP) to refurbish the digester and document the process. The AgSTAR program provided technical assistance.

PROJECT HISTORY

Langerwerf Dairy is a 400-cow family run dairy in Durham, California with a plug flow anaerobic digester that has been in operation since 1981. The anaerobic digester system includes a collection/mix tank with a transfer pump, a plug flow digester, a post-digester solids separator with solids storage system and a biogas-fired engine-generator.

A Caterpillar G3306 engine generator has operated about 90% of the project lifetime, averaging about 40 kW output. In 16 years of operation the digester has produced about 3,400,000 m3 (120,000,000 ft3) of biogas 2,000,000 m3 (72,000,000 ft3) of methane and the engine converted the biogas into 5,000,000 kWh of electricity. As of January 1999 approximately 17,600 m3 (23,000 yd3) of digested fiber have been sold.

The digester, generation and solids separation system cost $200,000 in 1981 Since 1981, the farm spent about $160,000 on operation and maintenance including this $50,000 project. Annualized operation and maintenance of the whole system considering a 4% inflation rate is about 4% of capital costs. Since 1981 the system has produced $350,000 worth of electricity; sold approximately $138,000 of digested fiber; replaced $75,000 of heat with hot water recovered from the engine; and saved $135,000 in lagoon cleanout costs. The net cash return for the 16 years of operation is approximately $540,000.

DIGESTER DECONSTRUCTION

After 16 years the digester gas production had decreased. Leaks in the gas collection cover and solids accumulation were the suspected cause. The refurbishing project fieldwork began on October 14, 1998. The perimeter chain link fence, protective greenhouse (2-layer clear plastic over galvanized steel hoops) and gas collection cover were removed over a one-week period.

The floating crust under the gas collection cover was 3 - 5 feet thick and supported the weight of a man. About 270 m3 (350 yd3) of crust was removed by a trackhoe and hauled to cropland with farm dump bed trucks. This required 2 days and 4 people plus the trackhoe operator.

The remaining digesting slurry was pumped out, with 152 m3 (40,000 gal) reserved in a nearby tank for digester startup. 1.5 m (5 ft) of settled sludge was covering the digester floor and part of the heating system. The black steel hot water heating system was examined and found to be in good condition.

Approximately 308 m3 (400 yd3) of sandy sludge were in the digester and approximately 254 m3 (330 yd3) were removed using a hydraulic mining technique. High-pressure hoses using recycled digester water were used to wash sludge solids to a pump that pumped the mixture to a temporary settling basin near the digester. Clarified liquid flowed back to the digester.

Cleaning out the sludge required about 10 days because several different approaches were tried, before arriving at the workable solution. The successful hydraulic mining with recycle required 4 men for 5 days.

The floating crust and settled solids reduced the usable volume of the digester by about 66%.

COMPONENTS AND MATERIALS AFTER 16 YEARS OF OPERATION

Once the digester was emptied all components were inspected for serviceability.

Gas collection cover. The hypalon gas collection cover material degraded and finally failed due to UV weathering. UV weathering caused pinholes and subsequently biogas and water infiltrated into the cover fabric creating larger holes and leaks.

Gas collection cover attachment. Black flat bar steel, angle iron and galvanized bolts were used to attach the cover to the concrete tank. Sheet metal capping installed on the top of the digester wall had rusted away. The atmosphere inside the greenhouse is moist and includes some hydrogen sulfide volatilized from the effluent end of the digester. Some manure had run between the cover and the digester wall and remained in contact with the bolts for many years. At least a dozen bolt heads had corroded enough to require drilling out. Some of the flat bar steel had corroded because it was left in contact with manure and air. Most of the angle iron was rusty but not corroded significantly. New hardware was used for cover reattachment.

Concrete. Some concrete corrosion was found in the same areas as the cover attachment corrosion and is attributed to manure that had run along the concrete wall. The manure decomposed forming acids that etched away one eighth to one quarter of an inch of concrete over a 12 m (40 ft) length of wall. The corrosion presented no problem with the digester operation.

Liner material. Hypalon material was used for the digester liner. The material was judged to be suitable for continued service. It was aged and grainy in spots but did not exhibit the holes or liquid infiltration. No buildup of struvite was found.

Heat exchanger and pipe. The digester heat exchanger was constructed of black steel. It was found partially buried in sandy sludge and judged to be not fully effective. Upon removal of the sludge no external corrosion was found.

Gas collection pipe. No degradation of any PVC plastic including the gas collection pipe was found. The gas intake where the cover rested was slightly deformed, probably due to 16 years of the cover resting on it and being exposed to high temperatures. There was some accumulation of manure solids evident in the gas line probably from foaming during startup.

Greenhouse components. Galvanized greenhouse support hoops were mildly corroded at unprotected welds. The corrosion can be attributed to condensation mixed with some hydrogen sulfide. The hoops were replaced. The greenhouse plastic was 4 - 5 years old, at the end of its useful life, and was replaced.

RESTARTING THE DIGESTER

A pipe coupling in the heating system was broken during the cleanout process and later was repaired. The digester was refilled on 10/22/98 with new and old manure. Heating began on 10/23 with the engine-generator running on propane. The new digester cover was installed using new steel and bolts on 10/28. On 10/29 the digester temperature was at 29° C (85° F) and 5% new manure was added. The digester gas meter was installed and the biogas gas tested in a flame test the same day. The flame was consistent and had good color characteristics. Late on 10/29 the biogas was tested in the engine. Full power was demonstrated and therefore the engine was set at 20 kW and run continuously on biogas. Table 1 shows the log of the startup of the digester.

By 11/1 the engine was running continuously at 30 kW, consuming 544 m3/d (19,200 ft3/d). The greenhouse was installed mid November to protect the digester during winter weather. On 11/30 engine output reached 52 kW at continuous operation.

CURRENT OPERATIONS

Digester operation and gas production improved after startup as the digester acclimated and reached full feed. Engine-generator operations improved as well and by January of 1999, the engine was operating at 55 kW. At the end of 1999 the engine was operating continuously at 62 kW.

Table 1 . Langerwerf Dairy Digester Startup Log

Date	**Cumulative Gas Meter Reading** m^3 (ft^3)	**Average output since last reading** m^3/d (ft^3/d)	**Effluent Temp – °C (°F)**	**Effluent pH**
November 3	2,720 (96,000)	544 (19,200)	34.4 (94)	7.3
5	4,572 (161,400)	914 (32,280)		
7	5,924 (209,100)	676 (23,850)	38.3 (101)	7.4
9	7,300 (257,700)	688 (24,300)	38.8 (102)	7.4

17	14,297 (504,700)	875 (30,875)		
18	15,252 (538,400)	955 (33,700)	39.4 (103)	7.4
27	24,476 (864,000)	1,025 (36,178)		

Table 2 shows the farm electricity purchases in September, October, and November 1997 and 1998. In 1997 the farm purchased 118-225 kWh/d. In September 1998 the engine-generator was shut down and the farm required 609 kWh of electricity per day. November 1998 saw biogas production increase and electricity purchases decrease to 109 kW/d. The digester electricity production saved the farm $850 in October alone. The 1998 purchases can be compared with the 1997 purchases and it can be seen that even with just startup operation, the farm is buying less electricity that in 1997. At the same time, the digester system produced about 1000 surplus kWh in November 1998 that were sold to PG&E for $356.27. The farm was not selling nearly as much electricity in 1997.

Table 2. Electricity Purchases Comparison 1997-8

Month	1997 kWh/d purchase	1998 kWh/d purchase
September	**194***	**609****
October	**118***	**502*****
November	**221***	**109***

* - generator operating, ** - generator not operating, ***- partial operation

EXPECTED COMPONENT LIFE

The project life was expected to be 20 years, based on the usable life of components in agricultural waste systems. However, review of components in place showed most components should continue to function for at least 10 more years. Table 3 summarizes the expected life of components based on what has been learned from the project.

REFURBISHING EXPENDITURES

The project was completed on time and on budget. Table 4 summarizes the actual expenditures. The situation found upon opening the digester necessitated altering some strategies and planned work. Hired labor was substituted for a contractor when it was obvious that mantime was more necessary than skilled construction assistance. Savings were used to spend more money on rental equipment for removing crust and settled solids. A trackhoe to remove crust saved money that was then used to hydraulically mine solids. AgSTAR assistance substituted for some of the planned farm personnel time. AgSTAR personnel suggested the recycle settling ponds, set up the cover for installation and worked with the cover installation crew.

Table 3. Original Component Life Estimate vs. Revised Estimate of Usable Component Life

Component	1982 Projected Life	1998 Remaining Life	Revised Estimate of usable life
Concrete	20 years	10+ years	30+ years
Steel plumbing	20 years	10+ years	30+ years
Plastic plumbing	20 years	10+ years	30+ years
Greenhouse plastic	3 years	0	4 years
Greenhouse galvanized steel	20 years	4 years	20 years
Gas collection bag	20 years	0	12 years
Engine – between overhauls	2 years	4 years	4 years
Gas meter	10 years	10 years	10 years
Gas pump	5 years	4 years	4 years
Project life	20 years	10+ years	30+ years

Table 4. Costs of Refurbishing the Digester

				Labor	Costs	
Tasks				Hours	$ per unit	Total
Disassemble system						
	Farm Labor	hours		213	$ 22.00	$ 4,686.00
	Hired Labor	hours		210	$ 12.00	$ 2,520.00
	Rent Mixer/Pumps	days			$ 75.00	$ 1,084.30
	Rental crane	days			$ 375.00	$ 920.00
	Farm truck /tractor	hours		40	$ 25.00	$ 1,000.00
Put system back together						
	Farm Labor	hours		156	$ 22.00	$ 3,432.00
	Hired Labor	hours		151	$ 12.00	$ 1,812.00
Consulting						
	AgSTAR					$ 9,800.00
	Project Manager	hours		100	$ 65.00	$ 6,500.00

Materials						
	meter	Roots				$ 1,250.00
	flare	Varec or equiv				$ 2,833.71
	cover	30 mill polypropylene				$ 4,603.71
	frame	angle	,clips, bolts			$ 630.46
	greenhouse parts					$ 2,750.04
Contingency purchases						$ 6,381.96
Subtotal						$ 50,204.18
Contingencies @ 10%						$ 0
TOTAL						$ 50,204.18

LONG TERM DIGESTER MAINTENANCE COSTS

The anaerobic digester portion of the system was installed for about $ 80,000. The mix tank, generator and solids separation system and solids storage cost an additional $120,000, for a $200,000 total. Since 1981, the farm spent about $160,000 on operation and maintenance including this $50,000 project. Annualized operation and maintenance of the whole system considering a 4% inflation rate is about 4% of capital costs.

Total digester maintenance costs experienced between 1981 and 1998 were less than $1,000. This project expended $50,204 in 1998 dollars. Assuming an average annual inflation rate of 4% for the 16 year period, $2,291/yr in 1981 dollars was the average annual cost. This value was calculated by discounting the expenditures to 1981 values and then dividing by the 16 years of operation. Therefore, the conservative long term annual digester maintenance cost is approximately 2.9% of capital cost.

SOLIDS ACCUMULATION

The accumulation of solids in a digester or lagoon is expected. Both are treatment facilities that are maintained at least partially filled and designed not to be cleaned out for many years. Lagoon sizing includes volume for bacterial treatment, rainfall, and the accumulation of sludge. Single cell lagoon sizing includes the above plus storage volume. A two cell lagoon separates the treatment and sludge accumulation volume in the first cell from the storage volume in the second cell. Stored manure is held until it can be completely removed at the appropriate interval.

The NRCS *Field Waste Management Handbook* (National Engineering Handbook, *Agricultural Waste Management Field Handbook*, USDA, Soil

Conservation Service, April 1992) page 10A-3, contains the method used to calculate sludge accumulation in anaerobic lagoon treatment systems. An anaerobic lagoon receiving the waste from 360 cows would accumulate 65,155 m3 (85,000 yd3) of sludge over the same 16-year period as the cleanout interval of the plug flow digester. A recent revision to Practice Standard 359-1 (*Natural Resources Conservation Service Conservation Practice Standard, Waste Treatment Lagoon Code 359*, January, 1998, Revision 4) distributed through the North Carolina State NRCS office, reduces the dairy sludge accumulation rate and for this comparison would yield 42,492 m3 (55,555 yd3) of sludge storage volume.

Approximately 566 m3 (740 yd3) of material (crust and sludge) accumulated over the 16 years of operation the plug flow digester while 42,492 m3 (55,555 yd3) to 65,155 m3 (85,000 yd3) of material would accumulate in a lagoon. Cleaning the digester and hauling off material in 10 yard (7.6 m3) dump trucks would require 74 truckloads while cleaning the lagoon would require 5,555 to 8,500 truckloads to remove sludge.

Therefore, over a 16-year period the dairy plug flow digester accumulated 97-99% less sludge than would be expected in an anaerobic lagoon.

The volume of accumulated sludge in a lagoon can be reduced 15-50 % if a solids separator is used. (National Engineering Handbook, *Agricultural Waste Management Field Handbook*, USDA, Soil Conservation Service, April 1992) At 50% reduction in solids using the lower North Carolina solids yield guidance, the lagoon cleanout at 16 years would still require 2,704 truckloads more than the digester cleanout.

If a farm has the option of a digester and separate storage or an anaerobic lagoon, the farm should be aware that additional volume for sludge storage is not required after the digester. Therefore the farm does not have to pay to build sludge storage volume. Any post digester settled solids are removed from storage when the storage is emptied. With a lagoon, the farm will have to manage 2,700 to 8,000 dump truck loads of sludge that a digester and separate storage do not accumulate.

CONCLUSIONS

The materials originally selected for digester construction were satisfactory after 16 years of operation and the majority of the material is serviceable for 10 more years. Therefore, the usable life of a plug flow manure digester should be at least 30 years. The estimated total system operation and maintenance cost is about 4% of capital costs annually, while the plug flow digester portion of the system cost was 2.9% of capital costs to operate and maintain annually. A digester with separate storage facility will be much smaller than a lagoon to treat and store the same quantity of manure. A digester system will accumulate less sludge than would be expected.