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# AERATION OF WHEY WASTES. I. NITROGEN SUPPLEMENTATION AND SLUDGE OXIDATION \*

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Treatment of whey wastes is generally considered a difficult problem, as evidenced by the fact that some 79 per cent of cheese plants have waste disposal problems (1). This is as true for small plants receiving less than 75,000 lb of milk daily as for larger installations. The magnitude of the problem was also indicated by Sanders (2) in 1947 when he estimated that 5,000 producers of cheese in the United States do not treat their wastes.

Some practical method of pretreatment of cheese factory wastes before discharge into small municipal sewer systems was recommended by Backmeyer (3). He cited the adverse effect of whey on an activated sludge plant even though the whey increased the daily BOD loading by only 11 per cent. According to Johnson (4) conventional sewage treatment processes adapted to cheese wastes are prohibitive in cost for the small cheese plant. Waste treatment must also be simple in operation and as nearly foolproof as possible. Bloodgood in 1948 (5) listed requirements for a satisfactory treatment plant and stated that it will take time and effort to accomplish the desired service.

Waste waters from cheese factories not treating whey wastes vary in BOD from about 700 to 5,000 ppm. At one time it was believed that the only prac-

tical method of getting rid of whey wastes would be anaerobic treatment (6), although such plants are not presently known to the authors. Lately, spray irrigation of whey has been reported to be successful in certain localities (7) and in this connection the Eastern Regional Research Laboratory has a contract study underway at the University of Wisconsin to determine under which conditions whey waste can be sprayed. Many cheese factories, however, are unable to dispose of waste waters directly on land and must resort to other disposal methods.

This report covers the successful treatment of whey wastes in the laboratory by biochemical oxidation. The techniques employed were those used in previous dairy wastes investigations (8)(9)(10)(11). Studies were made at different times on the same aerating sludge used for a period of 96 days in daily whey waste treatments.

## Experimental

The aerobic fermentors extensively used in the authors' previous work on dairy wastes again constituted the laboratory waste disposal units. An aerator-stirrer mechanism provided thorough aeration and agitation of 12 l of sludge-waste mixture in a glass jar. The temperature was maintained at 29 to 31°C by means of a controlled-temperature water bath. Excess air was supplied at the rate of 1½ volumes (18 l) per minute.

The sludge was propagated from an active aerobic culture obtained from an industrial dairy waste disposal unit.

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Daily additions of skim milk solids were made to the settled sludge after siphoning off the supernatant liquid. After 30 days of this treatment, the seed sludge was prepared by dispersing the cell solids with tap water. The supernatant wash water was drawn off and the settled sludge was distributed into each of two aerators to give a final concentration of 2,000 ppm sludge solids in 12 l.

The experiments were conducted so that 4 l of seed were retained in each aerator. To this, 8 l of solution containing 12 g dried whey were added in a one-dose feeding. Agitation and aeration were halted during the few moments of feeding. Values for zero starting time were obtained on samples of seed sludge and calculated for the starting volume of 12 l. Prior to sampling, adhering sludge solids were carefully brushed from the sides and bottom of the fermentor and dispersed throughout the solution. Water was added to the 12-l mark to replace evaporation losses. The mixture was agitated while the sample was removed by a siphon.

The experimental work was designed to study the rate of whey removal from solution as affected by nitrogen supplementation. Studies initiated on March 5 provided for two fermentations of mixed liquor composed of 2,000 ppm sludge and 1,000 ppm whey determined by the rapid COD test. A daily schedule of 12-g whey-solids (1,000 ppm) additions following effluent removal was maintained. The addition of 175 mg nitrogen as ammonium hydroxide to one fermentor gave a COD:N ratio of 30:1, as compared to 50:1 in unsupplemented whey.

On the 1st, 21st, and 96th days after whey feeding commenced, a schedule of analyses was followed to ascertain whether the supplemented and unsupplemented sludges were retaining their whey purifying abilities. Samples were removed 1/2, 2, 3, 4, 24, 48, and 72 hr after whey had been introduced. The total sludge-mixed liquor was as-

sayed for COD, suspended solids, and nitrogen. Suspended solids were determined by filtering 25-ml samples through tared asbestos mats on Gooch crucibles. The filtrates obtained were examined for COD and Kjeldahl nitrogen.

#### Whey Removal or Purification

Rates of whey removal in the three sampling periods were high. A sludge propagated on skim milk and one acclimatized to whey for several weeks removed more than 90 per cent of whey COD in 30 min, regardless of nitrogen additions. Within 2 hr the solutions were practically clear of soluble material as determined on the Gooch crucible filtrates. This points out the practicability of removing the clear effluent soon after feeding, as suggested by Kountz (12) and Eckenfelder (13).

In the first series, an average of 2,072 ppm sludge solids was used with 1,000 ppm whey. For proper sludge activity 7 per cent N is considered the minimum content required in a mixed liquor according to Helmers *et al.* (14). Therefore, 215 ppm nitrogen should be present. The empirical formula for sludge (8) shows that 124 units contain 14 units of nitrogen; hence the 2,072 ppm sludge should contain 234 ppm N. This plus 19 ppm introduced with the whey is more than sufficient to meet nitrogen requirements.

Table I presents changes in the COD of the suspended solids. The maximum increase was reached in approximately 30 min. Thereafter, steady decreases in the COD of the solids were observed. In general, not quite all the added whey COD was oxidized in 24 hr of aeration. Slight but noticeable increases in sludge concentration occurred.

Table II summarizes COD data on the amount of whey removed from solution, increases in suspended solids, and, by difference, the amounts of whey actually oxidized. Here, the rapidity and completeness of whey removal are again observed. This capacity of sludge to

**TABLE I.—COD Changes in Suspended Solids of Whey-Fed Sludge With and Without Added Nitrogen**

Time After Whey Feeding (hr)	COD Changes (ppm)					
	Whey Fed*					
	1st Day		21st Day		96th Day	
	No N	N	No N	N	No N	N
0†	2,567	2,337	4,810	4,794	4,952	4,952
½	3,494	2,942	5,492	5,343	6,059	6,084
2	3,388	2,570	5,469	5,222	5,722	5,969
3	3,069	2,561	5,401	5,133	5,672	5,537
4	2,763	2,525	5,328	5,213	5,597	5,567
24	2,628	2,525	4,678	4,718	5,462	5,280

\* 1,018 ppm whey COD.

† Before feeding.

store and assimilate nutrients had been demonstrated by Gellman and Heukelekian (15) and others (10). The storage product is a glycogen-like material and may approach one-third of the total cell weight (11). As this stored material is converted and oxidized for cell energy, the sludge solids gradually diminish.

The milk sludges exhibited the best ability to oxidize whey, showing 82 per cent oxidation in 4 hr. As the sludge was fed whey this oxidizing ability was slowly weakened, until by 96 days only

36 per cent could be oxidized in 4 hr. Added nitrogen was of some help; 67 per cent oxidation occurred, as compared to 50 per cent in 24 hr with the unsupplemented 96-day sludge. Although the older whey cultures are able to purify whey solutions quite readily, their impaired oxidizing ability would result in marked sludge build-up. The greater rate of oxidation by the milk-fed sludge may be attributed to the presence of substances in milk conducive to the rapid oxidation of whey.

### Sludge Stabilization by Oxidation

Changes in suspended solids were followed over a period of 72 hr from the time of whey addition. Figure 1 shows the stabilization of a skim milk sludge used for whey purification. Although the removal of whey from solution was not accelerated by nitrogen addition (Table II), ammonia did favor oxidation of suspended solids and hence stabilization of the sludge. This unacclimatized milk sludge was oxidized back to its starting weight of 2,064 ppm within 16 hr. The comparable unsupplemented sludge required 60 hr.

The 96-day whey-acclimatized sludge

**TABLE II.—Whey Removal, Whey Oxidized, and Suspended Solids Increase of Whey-Fed Sludge (as ppm COD)**

Time After Whey Feeding (hr)	Unsupplemented			N-Supplemented		
	Whey Removed	Susp. Solids Increase	Whey Oxidized	Whey Removed	Susp. Solids Increase	Whey Oxidized
(a) 1ST DAY						
½	907	927	—	935	605	330
2	1,018	921	197	1,018	233	785
3	1,018	502	516	1,018	224	794
4	1,018	196	822	1,018	288	830
24	1,018	61	957	1,018	288	830
(b) 96TH DAY						
½	930	1,107	—	955	1,132	—
2	1,018	770	248	977	1,017	—
3	1,018	720	298	961	585	376
4	1,018	645	373	966	615	351
24	1,018	510	508	1,018	318	700

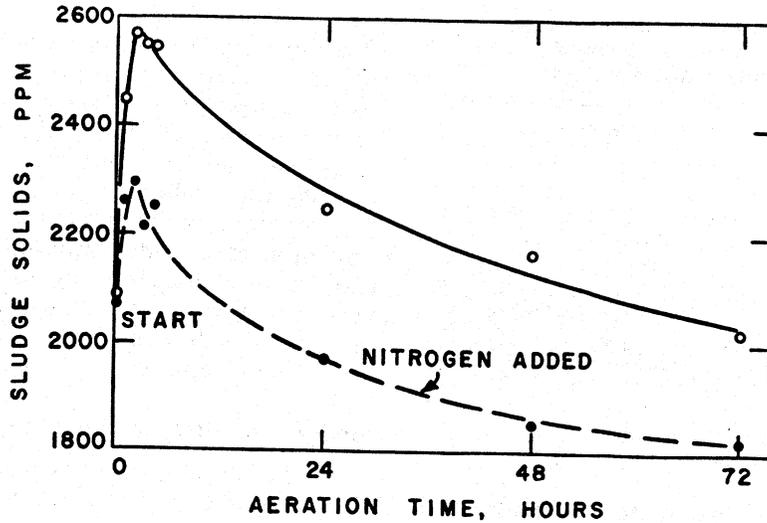


FIGURE 1.—Changes in sludge concentration during continuous aeration following whey addition (sludge cultivated in skim milk).

exhibited similar trends. Approximately 26 hr were needed for the  $\text{NH}_4\text{OH}$ -whey-fed sludge to return to its original weight, as compared to 60 hr for unsupplemented whey sludge (Figure 2).

Figure 3 shows the percentage of suspended solids oxidized by the milk and acclimatized sludges. These values are based on the sludge weights 2 hr

after feeding. By 70 hr, the percentage of sludge oxidized was about the same whether nitrogen-supplemented or not. Sludge oxidation reached 15 per cent within 24 hr in these tests, as compared to 23 per cent previously reported for dairy sludges (11), 23 per cent for pharmaceutical, 10 per cent for sewage, and 7 per cent for paper and pulp sludges (16).

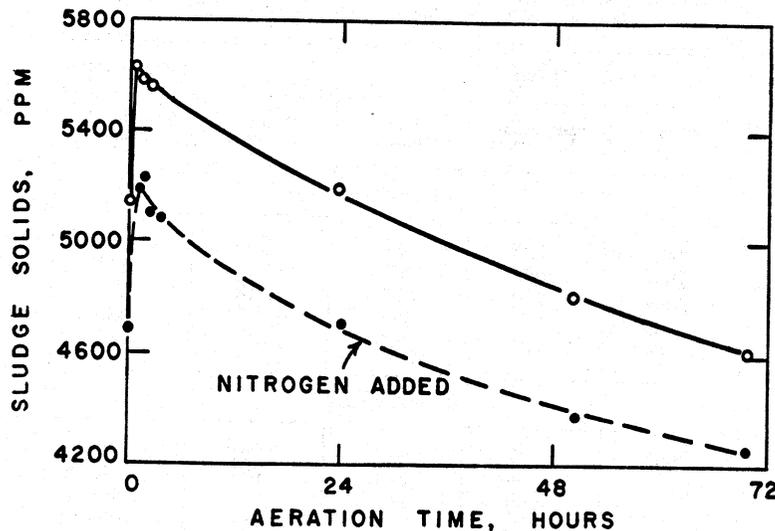


FIGURE 2.—Changes in sludge concentration during continuous aeration following whey addition (sludge cultivated 96 days on whey, with and without  $\text{NH}_4\text{OH}$ ).

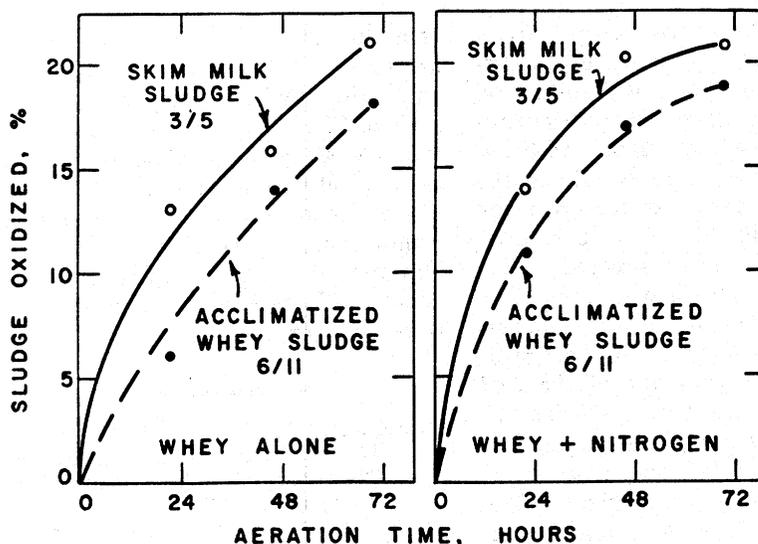


FIGURE 3.—Aerobic digestion of sludge immediately after whey feeding.

### Nitrogen

Nitrogen determinations were made on sludge mixtures and clear filtrates collected and prepared during the course of the experiments. Samples were inactivated by the addition of concentrated  $H_2SO_4$  and refrigerated until assayed by a semi-micro Kjeldahl method employing hydrogen peroxide and sulfuric acid digestion. The original sludge solution analyzed 200 ppm N, as compared to an estimated 234 ppm. Over the 72-hr aeration period, practically no increase in Kjeldahl-N occurred, even though N was added to the whey as ammonia.

The second run, made 21 days later after 15 feedings, showed practically the same N concentrations, yet the sludge concentrations had doubled. Excess N may have been oxidized to nitrates in the presence of excess organic matter, as had been demonstrated by Heukelekian (17).

The deterioration recognized in the 96-day sludges was reflected in nitrogen content. These sludges, which had begun to settle very poorly, contained 160 ppm N in the unsupplemented tank and 200 ppm in the other, although sludge solids measured 5,000 ppm.

These sludges still actively removed whey from solution; however, their nitrogen contents were only 3.2 and 4.0 per cent instead of the accepted minimum of 7 per cent.

### Discussion

Aerobic treatment of dilute whey wastes was successfully carried out in the laboratory. When 2,000 ppm sludge were used in treating 1,000 ppm whey waste under highly aerobic conditions, no additional nitrogen was needed to effect complete whey removal. Large quantities of sludge solids supply sufficient nitrogen from cell sources for the treatment of dilute whey. Although the COD:N ratio in milk is 18:1, whey can be treated with less nitrogen. A good source of N was shown by previous exploratory respirometer studies to be  $NH_4$ -N. Urea salts are a fair source, but nitrates were found of little use in oxidizing the lactose of whey. The nitrogen present in the sludge itself and in whey should be taken into consideration in calculating supplements.

The beneficial effect of nitrogen addition was illustrated during investigations in the 10,000-gal milk waste pilot

plant at Pennsylvania State University. When they were accidentally discharged into the treatment unit, excessive foaming immediately occurred and sugar was not oxidized. Addition of 100 lb of ammonium sulfate to the aerator on the days when the creamery wasted 5,000 lb of whey permitted treatment operations to proceed. This whey contained 350 lb of solids. The amount of nitrogen added was sufficient to give a COD:N of 17:1 disregarding the N of the whey and of the seed sludge. One-half the quantity of  $(\text{NH}_4)_2\text{SO}_4$  may have been ample.

It must be pointed out, that under actual plant conditions, unlike the laboratory experiments, a disposal unit would rarely receive pure whey solution for treatment. The raw waste from a cheese plant would most certainly contain floor washings, whole milk discharges, and probably some sanitary wastes. The introduction of these materials would be beneficial to the nutrient balance of the influent.

In pure whey studies, it was shown that a nitrogen supplement enhanced the rate of sludge oxidation, but under the laboratory schedule of daily whey feedings it was found that both supplemented and unsupplemented sludges gradually deteriorated and presented serious bulking problems within three months. Cheesemaking apparently removes from milk many known and unknown growth factors, leaving whey as an unbalanced food material for bacterial growth. Nitrogen alone replaces one of the most serious deficiencies, but in itself is incomplete supplementation. Other pure nutrient supplementation would be both impractical and probably incomplete. It is possible that periodic but judicious additions of milk itself may avoid the bulking problem.

### Summary

Dilute whey wastes (1,000 ppm) were aerated in the presence of a sludge (2,000 ppm) rich in nitrogen. Whey

of a COD:N ratio of 50:1 was treated as readily as whey supplemented with ammonium hydroxide to give a COD:N ratio of 30:1. A prolonged schedule of treating whey under laboratory conditions produced a change in the characteristics of the sludge. Sludge accumulation occurred as a result of impaired oxidation of intracellular material, although whey removal rates were not affected.

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