WASTE TREATMENT BY OPTIMAL AERATION—THEORY AND PRACTICE IN DAIRY WASTE DISPOSAL[1]

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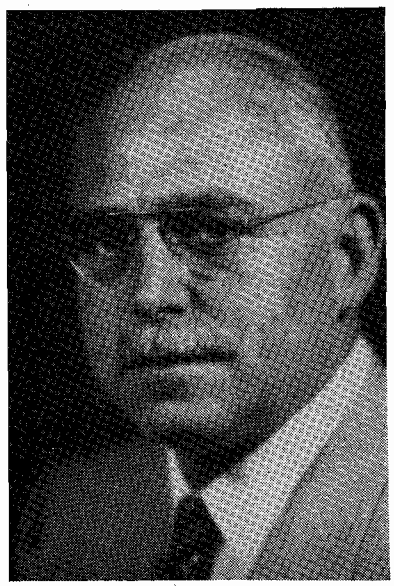
The activities of microorganisms on milk and other food products are well known. The activities of these same microorganisms when under control are of major importance for the disposal of fluid wastes from the food processing industries. Increasing demands for clean streams, rigorous legislation to counter pollution, dissatisfaction with existing waste disposal systems, and other factors led to an intensive study of the dairy waste disposal problem. The information obtained, the procedures developed, the principles involved, and the simplified dairy waste disposal unit which evolved from this research may be applicable to various organic wastes obtained during food processing. Table 1 compares various wastes, the concentrations varying with dilution.

The low concentration of solids in dairy wastes, the relatively great oxygen demand and the biochemical availability of the major constituents of the waste suggested an aeration treatment. Biological oxidation is not novel. Waste disposal by aeration is an accelerated natural process converting soluble organic polluting substances to harmless material. The process hinges upon the activity of microscopic life that feed upon the organic matter present in the waste waters and that require oxygen to maintain this life activity.

Details of our studies on the disposal of dairy wastes are available in a number of articles listed and summarized in reviews and discussions (2,8,13,14,15). This presentation gives selected basic concepts and their application to a waste disposal problem.

THRESHOLD EXPERIMENTS

Laboratory investigations using synthetic waste and conducted under vigorous agitation and adequate aeration showed that desirable changes take place rapidly. Aerobic treatment converted the much diluted high oxygen demanding materials to removable substances of lower oxygen requirement. Rapid chemical methods of analyses were necessary to follow the fast changes. A simplified chemical oxygen demand (C.O.D.) test became an important tool (17).



Dr. Porges received the B. S. degree from the University of Massachusetts in 1924, and the M.S. and Ph.D. degrees in Microbiology from Rutgers University. He has been employed by the U. S. Department of Agriculture since 1937, except for a period of 3 years. Dr. Porges presently is a chemist at Eastern Utilization Research Branch at Philadelphia, Pa., and is leader of the Dairy Waste Unit. He is the author of numerous publications and is a member of the American Chemical Society, American Association for the Advancement of Science, the Society of American Bacteriologists, Iowa Academy Science, and The Society of Sigma Xi.

Repeated tests conducted in a 5-gallon fermentor on a fill-and-draw procedure in which 1/5 of the mixed aerated solution served as seed gave the results shown in Figure 1. About 50 per cent of the oxygen demanding material had disappeared in 6 to 8 hours yielding a supernatant solution containing less than 10 per cent of the original C.O.D. (5). Later, it was shown that by increasing the seed concentration to 1000 ppm, the change was completed in about 3 hours (3). Increasing concentrations of active sludge should have a direct bearing on the rate of removal and conversion of the waste.

Table 2 is a solids balance obtained during continuous flow studies. Practically all of the protein-nitrogen of the waste was found in the the sludge, and all of the lactose had disappeared. The sugar consti-

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tuted all of the total organic matter that was destroyed (6).

Manometric studies gave further insight to the process. The rate and extent of oxidation were followed at 30° C., the temperature at which most of the laboratory studies were made since changes occur more rapidly at this temperature than at lower temperatures.

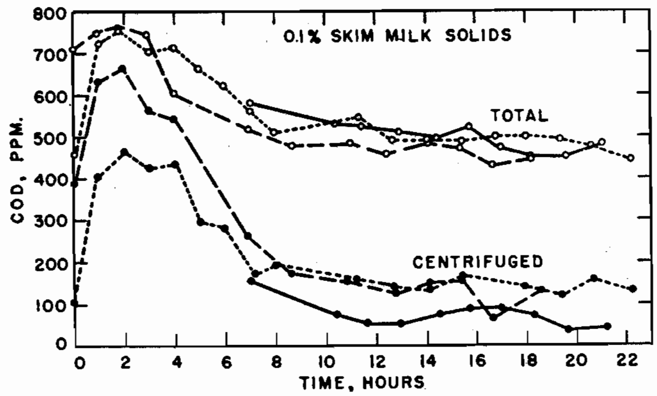

Figure 1. Changes in C.O.D. during filling operation. Seed, 1 gal. 500 ppm solutions. Feed, 4 gal. 100 ppm skim milk added in 4 hours.

TABLE 1 - COMPOSITON OF WASTES (APPROXIMATED FROM LITERATURE)

Type of waste	C.O.D.	B.O.D.	Nitrogen
	(ppm)	(ppm)	(ppm)
Dairy	1050	700	59
Tomato	1180	800	15
Food	1150	780	22
Brewery	1330	890	74

TABLE 2 — ORGANIC SOLIDS BALANCE DURING AEROBIC ASSIMILATION

	Protein units	Carbohydrate units	Total units
Influent feed	35	53	88
Effluent			
Cell solids	34	7	41
Solubles	1	2	3
Organic destroyed	0	44	44

TABLE 3 — ANALYSIS AND EMPIRICAL COMPOSITION OF WELL-AERATED SLUDGE

	Analysis	Ratio of atoms	
	(per cent)	(%/atomic weight)	
C	47.26	3.94	4.9
H	5.69	5.65	7.0
N	11.27	0.81	(1.0)
O	27.0	1.69	2.1
Ash	8.61	------	----

Empirical formula = $C_5H_7NO_2$

The data in Figure 2 were obtained when 3 mg. skim milk, or 1.5 mg. lactose, or 1.05 mg casein were agitated in Warburg respirometers containing 500 ppm well aerated sludge (4). Oxygen removal was very rapid, tapering off by the 6th hour, when it approached the rate of oxygen consumed in the flask containing no added nutrients (endogenous respiration). Analyses made at that stage showed that all of the organic substances were removed from solution. Yet, the actual amount of oxygen utilized failed to show complete oxidation. Many such tests showed that on the average about 37 per cent of the C.O.D. was destroyed by oxidation. Apparently the remainder of the organic matter was assimilated by the growing cells since the oxygen used was equivalent to the CO_2 evolved. Thus this oxidative conversion may be stated as follows: Organic wastes + $O_2 \xrightarrow{\text{organisms}}$ Cells + CO_2 + H_2O

EQUATIONS OF CONVERSION

The ultimate cell or sludge results from many intricate steps, but for practical purposes cell synthesis was expressed in a simple manner (7). Analysis of aerated sludge gave the empirical composition shown in Table 3. The complex system of a microbial cell is graphically simplified by the formula $C_5H_7NO_2$ which is of use for determining its relationship to available nutrients.

Lactose is completely oxidized to carbon dioxide and water: $C_{12}H_{22}O_{11}.\ H_2O + 12\ O_2 \rightarrow 12\ CO_2 + 12\ H_20$, or $CH_2O + O_2 \rightarrow CO_2 + H_2O$

Five of these sugar fragments and nitrogen are needed to produce a "mole" of cell:

$$5\ (CH_2O) + NH_3 \rightarrow C_5H_7NO_2 + 3\ H_2O$$

The Warburg studies showed that 3 out of 8 carbons were completely oxidized while 62.5 per cent or the remaining 5 carbons were assimilated. The following equation satisfied these conditions and agreed with the respiration quotient (R.Q.) showing that the CO_2 evolved was equivalent to the O_2 used. The 240 atom units of sugar yield 113 units of cell or 124 units when ash is included. This is 52 per cent by weight and approximated yields obtained in earlier experiments.

$$8\ (CH_2O) + 3\ O_2 + NH_3 \rightarrow C_5H_7NO_2 + 3\ CO_2 + 6\ H_20$$

Casein gave a like relationship. The casein analyzed $C_8H_{12}N_2O_3$ (omitting P and S) giving a "mole" weight of 184. Upon complete oxidation the following is obtained:

$$C_8H_{12}N_2O_3 + 8\ O_2 \rightarrow 8\ CO_2 + 2\ NH_3 + 3\ H_2O$$

But, manometric results showed only 3 carbons were

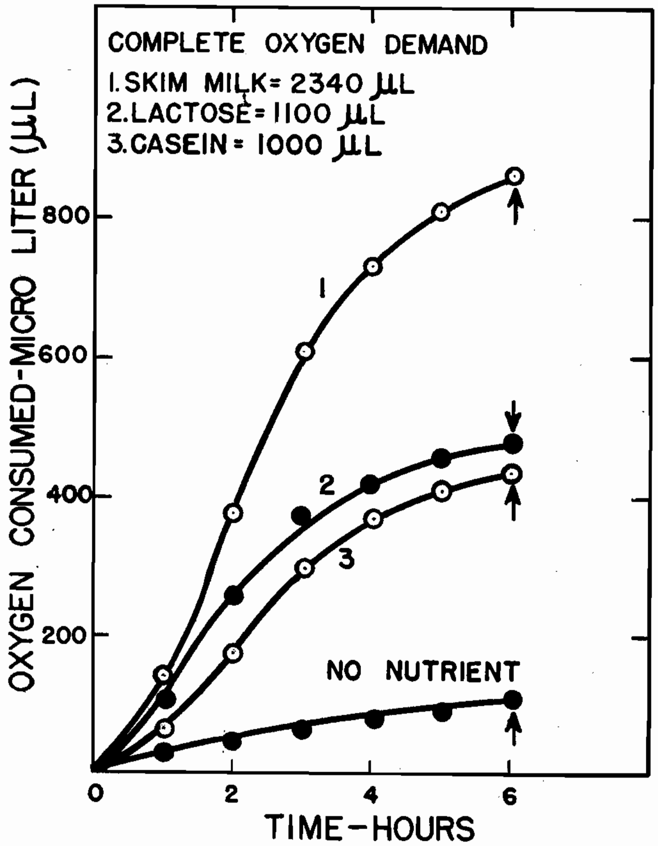

FIG. 2

Figure 2. Manometric studies for period of 6 hours showing immediate high oxygen demand and incomplete oxidation of substrate.

oxidized while 5 carbons were assimilated, thus protein conversion may be written:

$C_8H_{12}N_2O_3 + 3\ O_2 \rightarrow C_5H_7NO_2 + NH_3 + 3\ CO_2 + H_2O$

One mole of cell is produced from 240 units of sugar or from 184 units of casein. Fortuitously, lactose and casein occur in our synthetic waste in the same proportions. The nitrogen liberated in the oxidation of casein satisfies the nitrogen required for the assimilation of sugar. The equations were added together giving:

$8\ (CH_2O) + C_8H_{12}N_2O_3 \quad + 6\ O_2 \rightarrow 2\ C_5H_7NO_2 + 6\ CO_2 + 7\ H_2O$

Endogenous respiration or the oxygen requirement of the unfed cell was also determined and may be expressed:

$C_5H_7NO_2 + 5\ O_2 \rightarrow 5\ CO_2 + NH_3 + H_2O$

One "mole" of cell weight 113 (or 124 with ash) requires 160 units of oxygen for complete oxidation. Endogenous respiration proceeds at a much slower rate than assimilative oxidation. Experiments showed that oxygen demand during endogenous respiration is about 1/10 the demand during assimilation. Cell breakdown occurs at the slow rate of one per cent per hour.

The laboratory results may be gathered and plotted as in Figure 3, where one dose of 1000 ppm milk is acted upon by 500 ppm sludge. For about 6 hours the organic waste is used and converted to cell material. At this time oxygen demand is very high. Then the oxygen demand decreases to about 1/10 the rate and the sludge cells are used up at the rate of 1 per cent per hour requiring about 100 hours to attain the weight of the original seed.

Tabulation of Data

Complete combustion of a pound of moisture-free and ash-free skim milk requires 1.214 pounds of oxygen. In other words, a pound of oxygen must be supplied to oxidize a pound of oxygen demand. This amount of oxygen must be dissolved in the waste for each 8 pounds of fresh milk that is spilled.

A pound of skim milk solids dissolved in 1000 pounds of water (*ca.* 120 gallons) yields a 1000 ppm concentration. When this is aerated and agitated in the presence of 500 ppm sludge, the following occurs.

During assimilation:

Portion of O_2 required	37.5%
Amount of O_2 used	0.453 lb.
Time elapsed	6.0 hr.
Hourly O_2 utilization	0.075 lb.

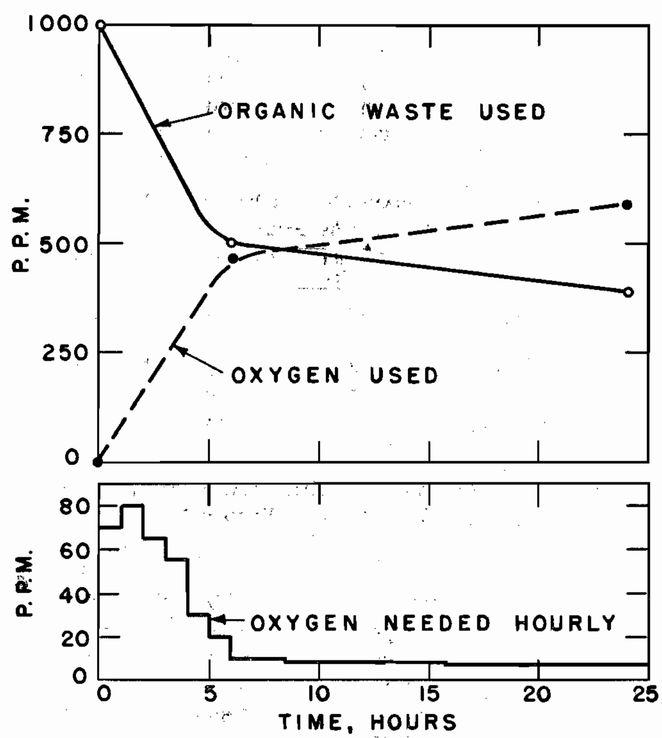

Figure 3. Compilation of laboratory experiments when 1000 ppm skim milk are aerated with 500 ppm sludge.

New cells (sludge) produced .... 0.5 lb.
During endogenous respiration:
Portion of O_2 required 62.5%
Amount of O_2 used .... 0.761 lb.
Time required to oxidize cells, *ca.* ....100.0 hr.
Hourly O_2 utilization .... 0.007 lb.

TREATMENT ON PILOT PLANT AND INDUSTRIAL SCALE

These data were applied to pilot plant studies by Kountz under a research project sponsored by the Department of Agriculture at the Pennsylvania State University. After 20 months of operation, treating 10,000 gallons of waste daily from the University Creamery, he reported that the original laboratory research data have been fully substantiated (10). Milk solids were oxidized in a few hours without any odor when sufficient oxygen was available. Oxygen was supplied by direct aspiration from the atmosphere by means of the Penberthy Ejector, type XL-96 size 7A (steam nozzle) which he selected after evaluating a number of non-mechanical proprietary aerating devices (11).

Excess sludge was no problem as it was oxidized. Since about 20 per cent of the sludge was destroyed by endogenous respiration daily, conditions were established wherein new cells produced from the milk solids in the waste replaced the amount oxidized.

Through the efforts and interest of Levowitz (12) the first commercial prototype was designed and put into operation by Kountz (9). The waste volume treated daily is 25,000 gallons in a tank of 37,500 gallons capacity with an effluent pipe at the 9,000 gallon level. The C.O.D. of the waste is about 2,000 ppm, the sludge concentration 5,500 ppm. Aeration is stopped for 6 hours to allow the cells to settle and the 25,000 gallon clear supernatant to drain out.

Endogenous respiration requires 9.4 pounds dissolved oxygen per hour and burns up 150 pounds of cells. During the 8 hours of waste flow containing 300 pounds of milk waste, 17 pounds of oxygen are required per hour during assimilation. Hence, a total of 26.4 pounds oxygen are supplied during the first 8 hours, and then only 9.4 pounds per hour for the remaining 10 hours. The 150 pounds of cells produced replace the 150 pounds destroyed.

The process is practically automatic and, if not tampered with and if left undisturbed, works to the satisfaction of all concerned. It must be emphasized that decreasing the air, or decreasing the periods of aeration, especially when overloading, produces conditions both undesirable and unnecessary in a waste disposal plant. (One pound of oxygen demand requires one pound of oxygen to be dissolved in the oxidation system.)

DISCUSSION

Non-odorous treatment of dairy and other food wastes is not only a possibility but an actuality. Inoffensive conditions are maintained when sufficient oxygen is supplied in solution to satisfy the oxygen demand. This accelerated aeration process satisfied the high oxygen demand during the short assimilation period and utilizes endogenous respiration with its low rate of oxygen demand for sludge digestion. Information obtained from these laboratory studies has been of value not only in designing units for the disposal of dairy waste but also in designing facilities for the aerobic biological treatment of other organic wastes (1).

Since complete oxidation has been stressed, waste removal or purification has not been discussed, although the rate of purification can be 10 times that of oxidation (8). Sludge can store large quantities of C.O.D. as glycogen-like substances in a very short while (16). These stored products then go through the process of assimilation and endogenous respiration. Cells may be removed in the early stages, but must be disposed of by means other than endogenous respiration.

A one-tank fill-and-draw, rapid aeration system, properly designed is a simple method of waste disposal with no disagreeable end products. A continuous process incorporating these principles is under development.

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