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ABSTRACT

Oysters are filter-feeding organisms which can accumulate substances to concentrations far above those found in the surrounding water. Large acreages of estuary bottoms have been classified as restricted for shellfish culture due to the presence of pollutants in the water and therefore, the likelihood of high levels of pollutants in oysters grown in those environments. Depuration is a natural process whereby oysters and other shellfish cleanse themselves of accumulated contaminants when they are placed in a clean environment. Recent studies have shown that bacterial depuration of oysters is feasible for the waters of Chesapeake Bay. Depuration is not possible, though, when water temperatures are below 10°C. Furthermore, both the rate of depuration and the reliability of the process increase with higher temperatures for the 10° to 20° C range. Utilization of waste heat from power generating stations would allow depuration to continue during winter months and could improve the quality of the product during the spring and fall.

INTRODUCTION

Chesapeake Bay and its tributaries have been noted for an abundant and pleasing variety of seafood since the days of Christopher Newport. One important species is the Eastern Oyster, Crassostrea Virginica, which has been harvested by the Indians and the early settlers and others up to present times. It is a bottom dwelling organism that is unable to move after it has set or attached itself to a suitable hard surface. Consequently, these animals are highly susceptible to environmental changes, predators and pollution. Natural populations in the estuaries of the Chesapeake Bay system are limited by low salinities occurring in the upriver sections. Areas wherein the end of summer salinity is greater than 15 parts per thousand experience high mortalities due to both predators and disease [1]. As a result oysters exist in large numbers only in those reaches of the estuaries characterized by moderate to low salinity.

The oyster is a filter-feeding organism that strains food from the water it pumps. A portion of the solids is digested and eventually voided as feces; the remainder is released immediately at the oyster's mouth and is called psuedofeces. The amount of feces and psuedofeces produced will be a function of the turbidity of the water and the pumping rate of the oyster. Pumping rates can be very high (greater than thirty liters per hour) at some periods, but a more typical rate would be 5 to 10 liters per hour [2]. Material filtered from the water by the oyster may contain substances other than food particles. In particular, compounds associated with suspended sediments, e.g. bacteria, heavy metals, and pesticides, will tend to be accumulated, but dissolved compounds can be taken up too [3]. Because during a single day, an oyster will pump a volume of water much larger than its body volume, concentrations can be greatly magnified. This process of accumulating water constituents to concentrations much higher than those found in the surrounding water is often called bioconcentration. The levels found in the oysters will be dependent not only on the amount of the substance in the water and sediment, but also on the availability to the oyster [4]. The concentration factor will vary from one water constituent to another and will tend to increase as the pumping rate increases.

DEPURATION

Depuration, the natural process whereby oysters and other shellfish cleanse themselves of accumulated contaminants when placed in a clean environment, is essentially the reverse of bioconcentration. Just as the uptake of water constituents is dependent on the amount and availability of the compound and the biological activity of the oyster, so too does the depuration rate vary with each substance and the pumping rate of the oyster. Chemical compounds which are incorporated into the flesh of the oyster require long periods, say several months to a year or more, to be purged. Pathogens, however, are believed to reside in the intestines of the oyster and in the mantle fluid. Depuration of bacteria and viruses can be accomplished in a relatively short period of time. Many states have regulations which permit shellfish from polluted waters to be relaid in clean water. In Virginia, the oysters must remain in the clean waters for two weeks, when water temperatures are above 50°F, before they can be reharvested and sold. Since the oysters must be harvested twice, labor costs are high. In addition, some portion of the original harvest is lost by death and because it is difficult to recover 100% of the oysters which are placed on the approved bottoms. For these and other reasons, very few commercial operations employ depuration in the natural environment.

Depuration in a controlled environment has been studied since the turn of the century, and has been practiced in England and France, and at selected sites in the United States, for many decades [5]. Many studies have been made to demonstrate the feasibility of bacterial depuration for hard clams (Mercenaria mercenaria), soft-shelled clams (Mya arenaria) and oysters (Crassostrea virginica) for locations ranging from Maine to the Gulf of Mexico. In general, these studies have shown that bacterial levels can be reduced to suitable levels within about 48 hours [5, 6, 7, 8, 9, 10]. Depuration plants of a commercial scale are in operation at this time in the states of Maine, Massachusetts, New York, New Jersey and Delaware.

VIMS Depuration Studies

For the past three years, studies have been conducted at the Virginia Institute of Marine Science (VIMS) to determine the necessary environmental conditions to achieve bacterial depuration of oysters in the Chesapeake Bay region [11]. In these studies and most others, pathogenic organisms were not measured. Rather members of the coliform bacteria group were used as "indicator organisms" for the presence of fecal pollution and therefore the likely presence of disease-producing organisms. Water quality standards also are usually given in terms of total and/or fecal coliform counts. Since the fecal coliform group is more closely correlated with fecal pollution, all data presented in this report are for the fecal coliform group as determined by the multiple tube fermentation technique [12]. Coliform levels are measured as MPN (Most Probable Number) per 100 milliliters of water or MPN per 100 grams for oysters.

Initial studies were made using small numbers of oysters in laboratory size trays. Later experiments were carried out with commercial scale tanks. Four different tank designs were tested. The following water quality measures were monitored: temperature, phytoplankton and suspended solids concentrations, dissolved oxygen, and salinity. Seawater was taken from the York River estuary and sterilized by ultraviolet irradiation. Fecal coliform levels in the oysters were measured at 0, 24, 48 and 72 hours. No standard for fecal coliform counts in oyster meats has been set by the federal and state regulatory agencies. The allowable number of fecal coliforms in hard clams in the interstate market has been set at 50 MPN per 100 grams. In the absence of any other criterion, the hard clam standard was used to determine whether individual depuration runs had been successful or not.

The two factors which had the greatest effect on 72 hour coliform levels were water temperature and initial coliform count. Within certain limits, none of the other factors appeared to either facilitate or hinder depuration. Dissolved oxygen (DO) levels close to zero were found to interfere with the depuration, and supersaturation is believed to be a potential problem since the release of the excess gas into bubbles could cause oyster mortality by embolism. However, if oxygen levels were above 2 mg/l and below saturation values there was no observed effect. Similarly, suspended solids concentrations ranging up to 77 mg/l were observed to have no impact on the depuration process. Exceedingly high concentrations of phytoplankton associated with algal blooms can deplete the oxygen supply and cause other problems, so that depuration during periods of blooms is not recommended. Successful depuration was observed for salinities ranging from 14 parts per thousand (ppt) to 22 ppt, although the actual lower limit is believed to be closer to 10 ppt. Waters with salinity ranging from 10 ppt to 35 ppt (seawater) can be used for depuration, although care must be used when there is a large change between the growing area and the waters used for depuration. In this case, a period of acclimation may be required before the oysters resume normal activity.

Water Temperature Effects

Several important changes are correlated with water temperature. First, the number of fecal coliforms found in estuarine waters tend to increase as the water is warmed. The reasons for this are not known, although increased boating activities might account for some of the change. The actual number of coliforms found at any given location and at any given time will depend on many factors, such as rainfall, flushing rates and so on, but the general trend is for bacterial levels to increase with water temperature.

Pumping, feeding and other biological activities of the oysters also are affected. Both bioconcentration and depuration are enhanced at elevated temperatures. The oysters used in most experiments were placed in a small, polluted subestuary and allowed to remain there until they had become contaminated. When water temperatures were above 25^{o}, concentrations as high as 79,000 fecal coliforms per 100 grams were observed in the oysters at the beginning of depuration. Since the water flowing through the tanks had roughly the same temperature, rates of depuration were similar to the uptake rates in the natural environment. Three experiments, conducted in July and September of 1975 with water temperatures of around $26^{o}C$, demonstrate the ability of the oysters to depurate large numbers of bacteria in a very short period. Initial coliform levels for both months were extremely high, but were reduced by around two orders of magnitude during the first 24 hours, as can be seen in Figure 1. Cleansing continued throughout the 72 hour experiments but at less rapid rates. Fecal coliform levels were below the 50 MPN/100 grams standard after 48 hours. Data presented in the figures are the mean concentrations for one or more experiments with multiple oyster samples taken for each sample point. The means were calculated using the procedure recommended by Velz [13].

Comparisons of depuration at differing water temperatures can be made only at low and moderate levels for initial coliform concentrations in the oysters, since naturally contaminated oysters rarely had high coliform counts when the water was cold. In Figure 2, data from experiments with water temperatures of about 15°C and 26°C and initial fecal coliform concentrations of around 3,000 MPN per 100 grams are compared. Although the 72 hour results are essentially equal, at the higher temperature the oysters depurated more rapidly at the beginning so that coliform levels were below the criterion after only 48 hours. Similar results were observed at initial levels of slightly under 200 MPN/100 grams, as shown in Figure 3. Since the initial levels were low, fecal coliforms were reduced to acceptable levels after only 24 hours for both the low temperature range (10°C to 12°C) and the high range (24°C to 26°C). However, the rate of depuration was more rapid and the final coliform levels lower at the higher water temperatures. Of the oysters depurated in the colder waters, 100% of the samples had 72-hour MPN levels below 100, but only 83% of the samples were below 50 MPN/100 grams. For those experiments having water temperatures above 20°C, 100% of the samples had less than 20 MPN/100 grams at 72 hours.

Sampling errors, changes in environmental factors during the three day experiment, natural variations between oyster populations and other factors all introduce variability in the experimental results. Therefore, it is difficult to make precise statements and conclusions. However, one can note several trends. First, the rate of depuration during the initial 24 hours is considerably greater than that observed during later periods. Second, the rate of depuration tends to increase and the final coliform levels decrease as the water temperature rises. Third, when initial coliform levels are equal, a larger percentage of the oysters is likely to achieve successful depuration in warm water than in cold water. Fourth, depuration is not recommended when the water temperature is below 10°C and only oysters that have low levels of coliforms should be depurated in the 10° to 12°C range. For the Chesapeake Bay region, this means that depuration plants should not be operated between the months of November and April, unless the water in the tanks is heated.

CLOSURE ZONES

In recent decades, the number of persons residing in the coastal zone has increased rapidly; generally the rate of increase has been greater than that for the nation as a whole. This population growth, coupled with industrial and commercial development, has produced ever increasing volumes of wastewater, most of which are discharged to the bays and estuaries. Although tidal flushing can produce rapid mixing and greatly dilute these waste streams, water quality has been degraded in many instances. As a result, many formerly productive shellfish beds have been rendered unsuitable for the culture of shellfish. For example, oysters taken from the Elizabeth River, which runs through the heart of the Norfolk, Virginia metropolitan area, had concentrations of zinc greater than 2,000 mg/l [3]. Presumably these abnormally high levels were the result of industrial discharges to this estuary. More frequently, growing areas have been declared unfit due to actual and/or potential health hazards. Surveys of water quality in shellfish growing areas are made on a regular basis by public health authorities. If water samples from an area consistently have high levels of indicator organisms, the area is closed for shellfish harvesting whether the source of the contamination is known or not. In other instances, estuary bottoms are closed because treated wastewaters are discharged to the overlying waters. Although disinfection is a required treatment method and is practiced at all sewage treatment plants, there still remains the potential for malfunctions and/or by-passes resulting in the release of pathogens to the environment. For these reasons a buffer zone normally is established around each treatment plant outfall.

For the purposes of discussion, these closure zones may be grouped in two categories: condemned areas and restricted areas. Condemned areas are those which have either a large wastewater outfall or high levels of pathogens. Since oysters tend to concentrate materials present in the overlying waters, oysters growing close to a large wastewater treatment plant outfall could contain undesirably high levels of such substances as heavy metals, pesticides, chlorinated hydrocarbons and so on. These are likely to present a health hazard to anyone consuming the oysters. Similarly the presence of a major domestic sewage treatment plant outfall or high levels of indicator organisms means that there is the very real possibility that shellfish taken from adjacent waters could contain disease producing organisms. The ability of oysters to depurate either pathogens such as viruses or compounds such as heavy metals and pesticides has not been demonstrated to occur over a several day period. Consequently, condemned areas are not suitable as supply areas for purposes of depuration.

Restricted areas on the other hand can be characterized by moderate to low levels of pollution, say 14 to 1,400 MPN/100 mls. This could be a semi-permanent situation, say due to a small wastewater discharge, or a temporary condition. For example, runoff from adjacent land often brings with it large numbers of bacteria. Consequently, during rainy periods, the levels of coliforms in the water may exceed standards. A maximum of 14 fecal coliform MPN/100 mls of water, has been set by the Food and Drug Administration as the upper limit for waters from which oysters are taken and placed in the interstate market. However, since depurations studies conducted at VIMS and elsewhere have demonstrated the ability of oysters to successfully depurate bacteria within 48 hours, oysters taken from the moderately polluted, restricted areas are suitable for human consumption after they have been depurated. In the states of Maine, Massachusetts, New York, New Jersey and Delaware federal and state public health officials have designated certain areas as suitable supply areas for depuration plants. Shellfish taken from these regions cannot be put on the market unless and until they have been depurated. These operations have been successful from both public health and economic points of view. The soft-shell clam depuration plant in Newburyport, Massachusetts has been in operations since 1931 [5], demonstrating that the process is indeed a practical one.

WASTE HEAT UTILIZATION

One adjunct of both population centers and industrial centers is power generating stations. Electricity is required for the homes, offices and factories located in the coastal zone and elsewhere. In other words, if there is a concentration of people and industry sufficiently large to cause water quality problems, it is also very likely that power generating stations exist within those areas and most likely they are located on the shores of the waterways. In particular, estuaries are prime locations for the large nuclear stations because of tidal oscillations. Tidal flows in the lower reaches of estuaries can be extremely large. Maximum tidal flows in Hampton Roads near the mouth of the James River, the southernmost major tributary of Chesapeake Bay, are roughly 100 times as great as the long term, average flow of fresh-water across the fall line at Richmond. Furthermore the tidal flows are roughly three orders of magnitude greater than the 10-year, low flows for the freeflowing portions of the river. The desirability of estuarine locations for large generating stations is readily apparent.

Water quality degradations associated with both treated sewage and industrial discharges have rendered many areas unsuitable for the culture of shellfish. At present the direct harvesting of shellfish is prohibited on approximately 500,000 acres of the Chesapeake Bay system. A little more than half is growing areas which are presently unproductive due to predators and other factors, but around 10% or the bottoms are designated as good for oysters. Additional areas, approximately 20% of the total, are listed as either fair for oysters or good for hard clams [14].

Studies of bacterial depuration of oysters conducted at VIMS, and studies of other shellfish at other locations, have demonstrated that depuration is feasible. The existence of commercial operations in New England for over forty years clearly shows the viability of the process. For the Chesapeake Bay region and those areas lying to the north, water temperatures during winter months are sufficiently low that biological activity of the shellfish is greatly reduced. Consequently, depuration is not possible during these periods. For the Chesapeake Bay and the eastern oyster, depuration is not recommended for water temperatures below 10°C. Utilization of waste heat from power generating stations would be an economical means of heating the water in the depuration tanks. In this manner, the operation of the depuration plant could continue throughout the winter months.

Since the rate of depuration tends to increase with rising water temperature, the fecal coliform levels at the end of the depuration period tend to be lower and show less variability at higher temperatures. Consequently, use of the waste heat to elevate water temperatures to around 20°C during the spring and fall could improve the final product of the plant. Since many power generating stations are situated on estuaries, it should be possible to find locations where environmental conditions are suitable for a depuration plant and waste heat is available. For example, a large fossil fuel station is located at Yorktown, Virginia on the York River estuary, only a few miles distant from the VIMS campus, where the present experiments were conducted.

SUMMARY

Many acres of productive estuary bottoms are restricted for the direct harvesting of shellfish. Although some of the closure zones are unfit for any shellfish culture, other areas are characterized by moderate to low levels of pollution. Shellfish grown in these areas could be cleansed of the accumulated bacteria in a properly designed and operated depuration plant. Operation of depuration plants in the Chesapeake Bay region is limited to periods when the water temperature is above 10°C. Utilization of waste heat from

power generating stations would provide an economical means of heating the water, thereby allowing depuration to proceed throughout the winter months. Supplemental heating of the water to about 20°C during the spring and fall is likely to improve the depuration process. Since many power generating stations are located within the coastal zone, at least a few stations should be so situated that an oyster depuration plant could be established in the same area.

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REFERENCES

1. Andrews, Jay D., 1970. "The Mollusc Fisheries of Chesapeake Bay (USA)". p. 847-856. In Proceedings of the Symposium on Mollusca held at Cochin, Part III. MAR: Brol. Assoc. of India

2. Haven, Dexter S. and Reinaldo Morales-Alamo - 1977 - personal communicat of unpublished data.

3. Moore, David J., 1969. "A Field and Laboratory Study of Fluoride Uptake by Oysters", Water Resources Research Institute of the University of North Carolina.

4. Huggett, Robert J., Michael E. Bender and Harold D. Slone, 1973. "Utilizing Metal Concentration Relationships in the Eastern Oyster (Crassostrea virginica) to Detect Heavy Metal Pollution". Water Research 7: 451-460.

5. Goggins, Phillip L., John W. Hurst and Peter B. Mooney, 1964. "Laboratory Studies on Shellfish Purification". Maine Department of Sea and Shore Fisheries. 18 pp.

6. Sterl, Bradford, Paul J. DeRocher and John W. Hurst, 1964. "Soft Clam Depuration Studies: Design and Operation of a Cleansing Plant". Maine Department of Sea and Shore Fisheries. 18 pp.

7. Huntley, Bob E. and Richard J. Hammerstrom, 1971. "An Experimental Depuration Plant: Operation and Evaluation". Chesapeake Science Vol. 12-4, p. 231-239.

8. Hefferman, W. Paul and Victor J. Cabelli, 1971. "The Elimination of Bacteria by the Northern Quahang: Variability in the Response of Individual Animals and the Development of Criteria". Proceedings of the National Shellfisheries Association, Vol. 61, p. 102-108.

9. MacMullan, Robert B. and James H. Redman, 1971. "Hard Clam Cleansing in New York". Commercial Fisheries Review, Vol. 33-5, pp. 25-33.

10. Devlin, I. H. and N. Neufield, 1971. "Oyster Depuration Plant, Ladysmith, BC". Report to the Industrial Development Branch, Fisheries Service, Department of the Environment, Ottowa. 71 pp.

11. Haven, Dexter S., Frank O. Perkins, Reinaldo Morales-Alamo, Martha W. Rhodes and Bruce J. Neilson, 1976. "Technical Studies on the Engineering and Biological Aspects of Controlled Purification of the Eastern Oyster". A report

to the U. S. Food and Drug Administration. 325 pp.

12. American Public Health Association, 1970. "Recommended Procedures for the Examination of Seawater and Shellfish". Fourth Edition, American Public Health Assoc., New York.

13. Velz, C. J., 1951. "Graphical Approach to Statistics: Evaluation of Bacterial Density". Water and Sewage Works, February, 1951.

14. Roberts, Morris H. Jr., Donald F. Boesch and Michael E. Bender, 1975. "The Chesapeake Bay: A Study of Present and Future Water Quality and its Ecological Effects". Final Report to the National Commission on Water Quality, VIMS, Gloucester Point, Virginia. 199 pp.

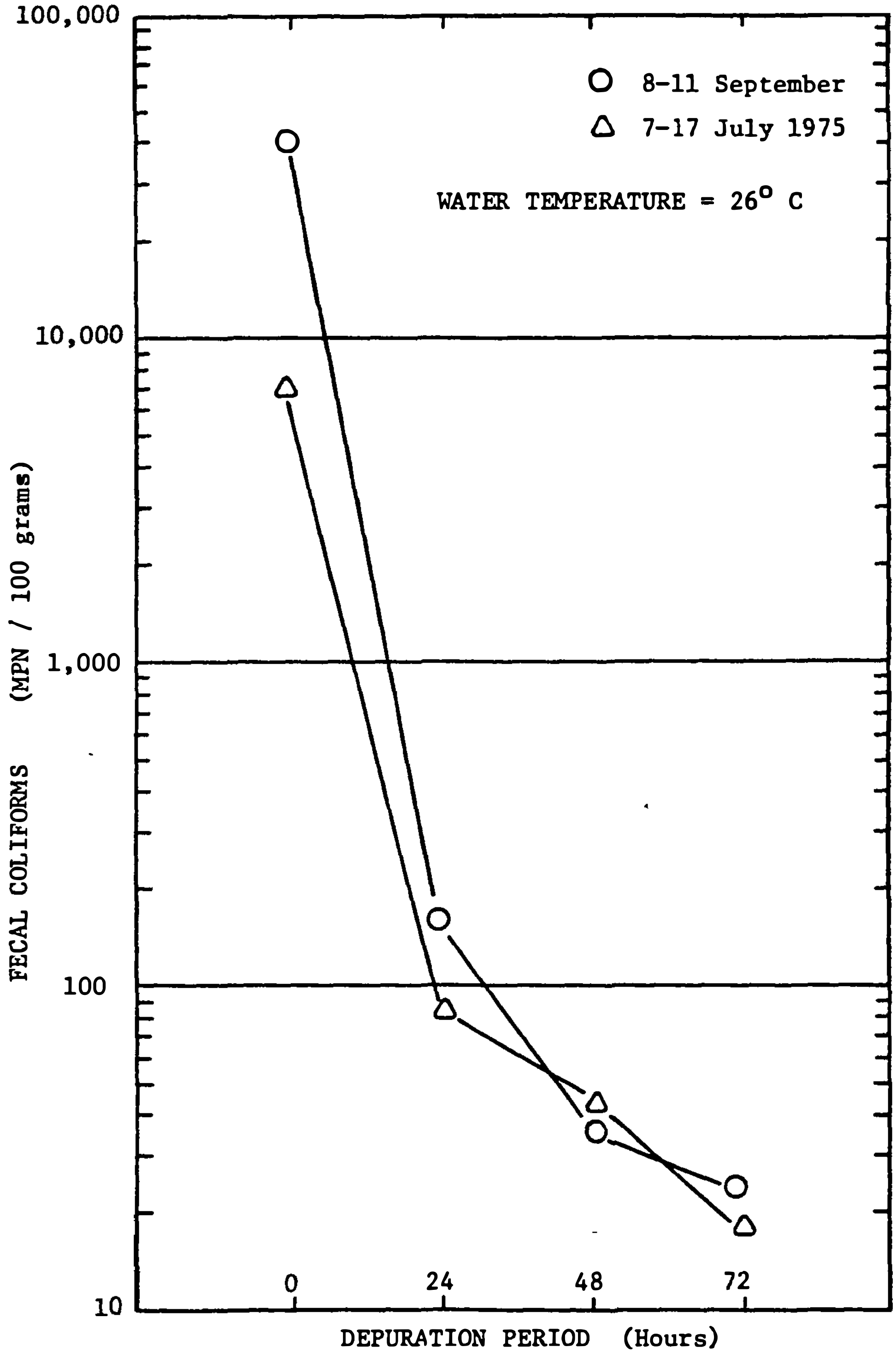

Figure 1. Comparison of Two Depuration Experiments at Elevated Water Temperature and High Initial Levels of Fecal Coliforms.

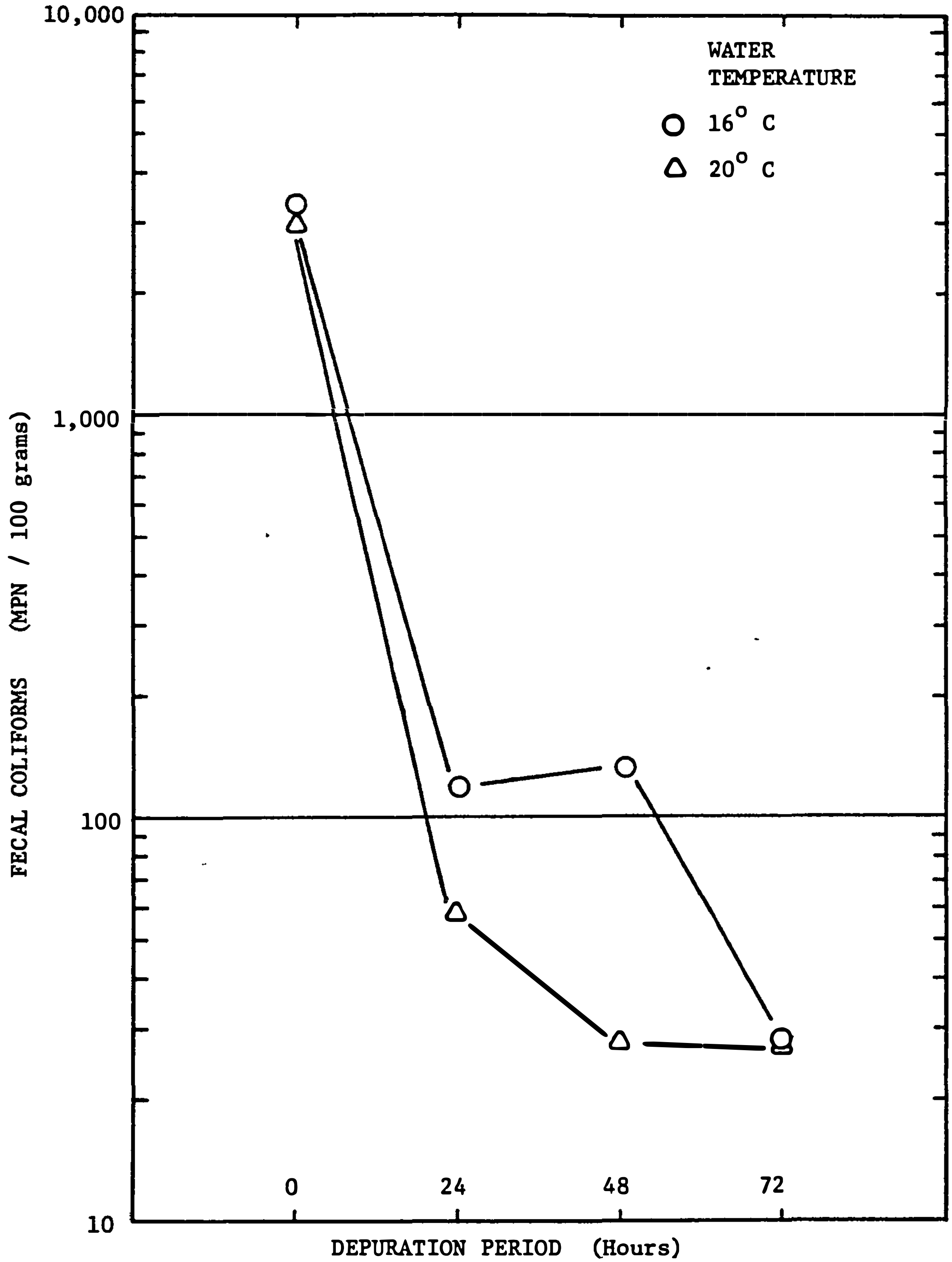

Figure 2. Comparison of Depuration at Two Water Temperatures with Moderate Initial Levels of Fecal Coliforms.

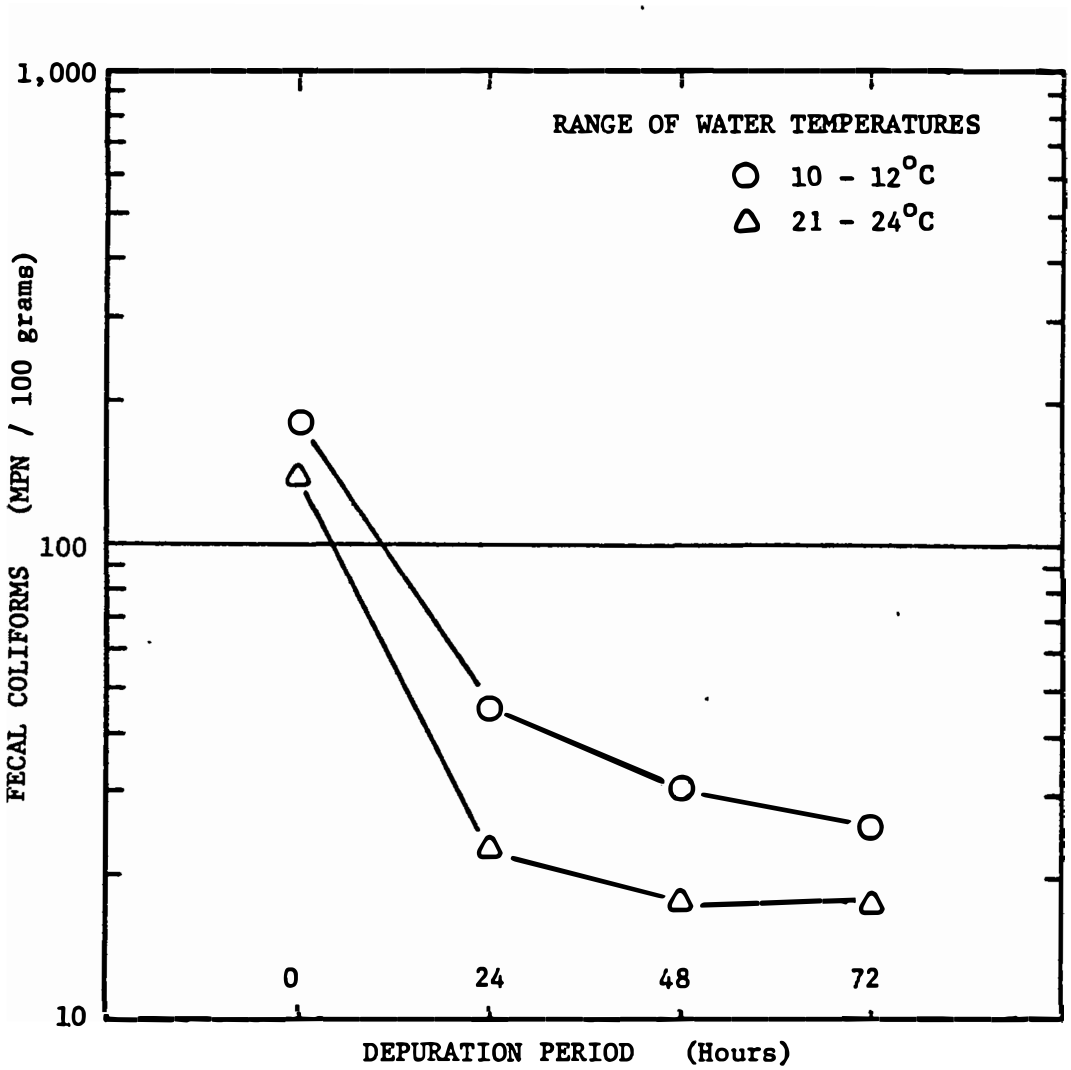

Figure 3. Comparison of Depuration for Two Temperature Ranges with Low Initial Levels of Fecal Coliforms.

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