Industrial Wastewater

FEATURES

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DEPARTMENTS

On the Cover
Industries in arid regions increasingly are recycling wastewater to conserve scarce water supplies.

Nitrifying High-strength Wastewater

Japanese pellet technology effectively treats nitrogen in animal and other high-strength wastewater

By Matias B. Vanotti, Patrick G. Hunt, J. Mark Rice, and Frank J. Humenik

In Japan, municipal wastewater treatment plants use a state-of-the-art technology — large populations of nitrifying microorganisms entrapped in polymer pellets — to nitrify ammonia quickly and effectively.

While U.S. municipal wastewater treatment plants tend to regard the nitrification–denitrification process as the most efficient and economically feasible way to remove nitrogen from municipal wastewater, the Japanese pellet technology exhibits tremendous potential for treating another kind of wastewater that is becoming increasingly problematic in the United States: wastewater from large-scale animal production facilities.

As the practice of confined animal production becomes more pervasive, effective and affordable alternatives for managing the nutrient byproducts of these operations are desperately needed.

Applying nitrification–denitrification treatment to animal wastewaters is difficult because high concentrations of ammonia typically present in these effluents inhibit nitrifying bacteria. Furthermore, nitrifying bacteria have a slow growth rate compared to heterotrophic microorganisms. In animal wastewater and other wastewater containing high biochemical oxygen demand (BOD), nitrifiers tend to become overgrown or washed out of reactors. Thus, retaining the slow-growing autotrophic nitrifiers necessary for nitrification–denitrification treatment requires recycling surplus activated sludge in an aerobic reactor or employing a long hydraulic retention time (HRT) — both of which are prohibitively expensive.

Aerobic treatment has been evaluated for treating animal wastewater, but in the absence of enriched nitrifying populations, aerobically treating high-ammonia animal wastewater may exacerbate environmental problems by stripping ammonia into the atmosphere.

Research indicates that immobilized pellet technology can nitrify animal lagoon wastewater at rates comparable to those found in Japan in municipal systems — rates that are three times higher than those achieved by conventional activated sludge treatment systems. In addition, the pellet technology is quick and relatively inexpensive.

Nitrifying Pellet Technology

The immobilization process provides an environment in which nitrifying microorganisms can perform optimally. Nitrifiers are entrapped in 3- to 5-mm pellets made of polymers that are permeable to the ammonia, oxygen, and carbon dioxide that the microorganisms need to thrive (see Figure 1, p. 31).

The pellets, typically made of polyethylene glycol and polyvinyl alcohol, are functional for more than 10 years. Wastewater is treated in a nitrification tank equipped with a whole-floor aeration system and a wedge-wire screen that retains the pellets, which comprise 7% to 15% of the reactor volume. According to Vanotti and Hunt (2000), immobilization technology also can be adapted to remove ammonia contained in anaerobic lagoons quickly and efficiently by using acclimated microorganisms.

Researchers conducted bench-scale tests to nitrify swine lagoon wastewater containing approximately 230 mg/L of ammonia nitrogen by employing nitrifying bacteria cultivated in a medium containing 300 mg/L of ammonia nitrogen and immobilized in the polymer pellets.

Nitrification efficiencies of more than 90% were achieved with a 12-hour HRT and an ammonia loading rate of 420 mg/L·d of nitrogen. High-ammonia nitrifying bacteria immobilized in polymer pellets successfully treated swine wastewater containing 350 to 2600 mg/L of nitrogen (Vanotti *et al.*, 1999). In batch treatment, ammonia removal rates of 917 to 1013 mg/L·d of nitrogen were obtained with 97% to 100% nitrification efficiency (see Table 1, below). Although these bench studies showed the extraordinary potential for using nitrifying pellets to remove ammonia from animal wastewater, pilot-scale testing was required to evaluate the most efficient operating strategy for a full-scale application.

Pilot Experiment

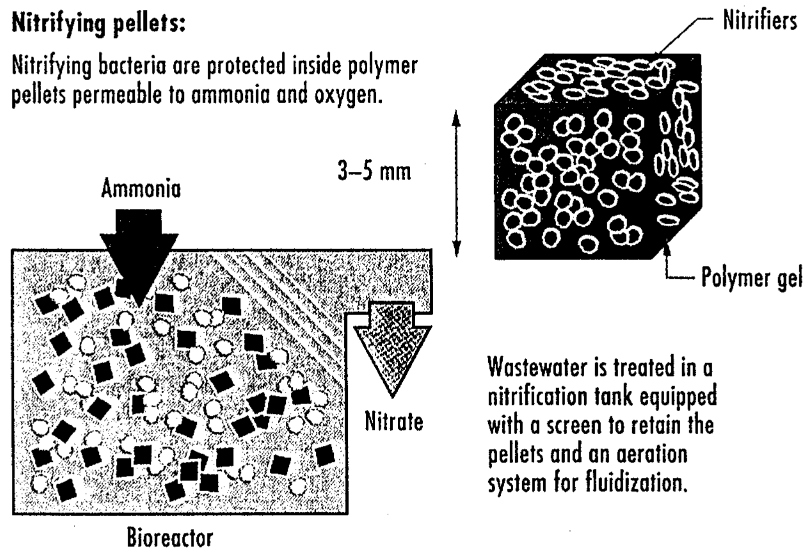
A pilot test was conducted at a swine production facility near Kenansville, N.C., using a nitrification reactor modeled after the Pegasus process (Takeshima *et al.*, 1993), which is commonly used in Japanese municipal plants (see Figure 2, p. 32).

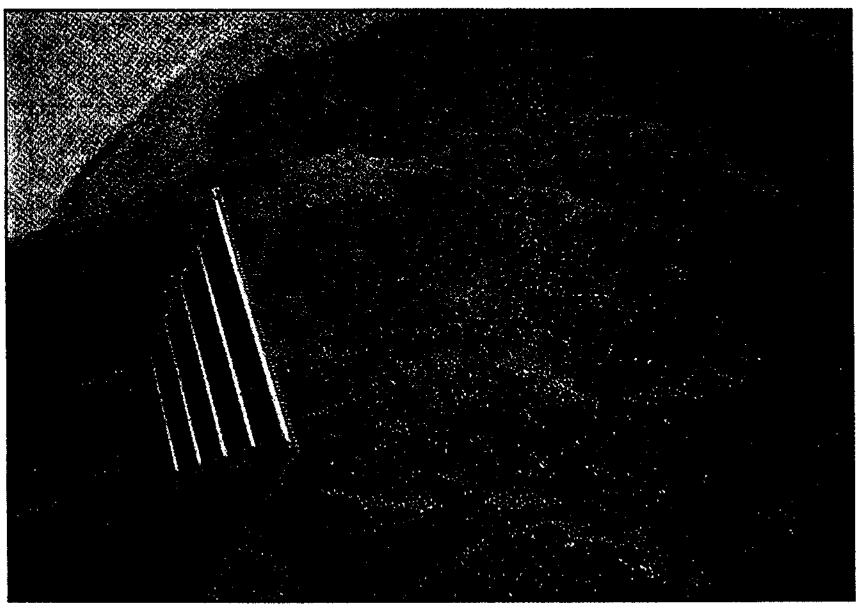
The pilot reactor consisted of a 0.34-m^3 contact aeration tank packed with polyvinyl chloride cross-flow media used to lower influent BOD; a 0.18-m^3 sedimentation tank; and a 1.3-m^3 aerated, fluidized nitrification tank containing 130 L of 3- to 4-mm polyethylene glycol nitrifying pellets manufactured by Hitachi Plant Engineering & Construction Co. (Tokyo). The unit was designed to treat 1 m^3/d of lagoon liquid and to remove 280 g of ammonia nitrogen from 15°C water.

A wedge-wire screen installed at the nitrification tank outflow separated the pellets and activated sludge and retained the pellets inside

FIGURE 1

How the Nitrifying Pellets Work





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Nitrifying microorganisms that are immobilized in 3- to 5-mm polymer pellets have been proven to treat high-strength wastewaters effectively for more than 10 years.

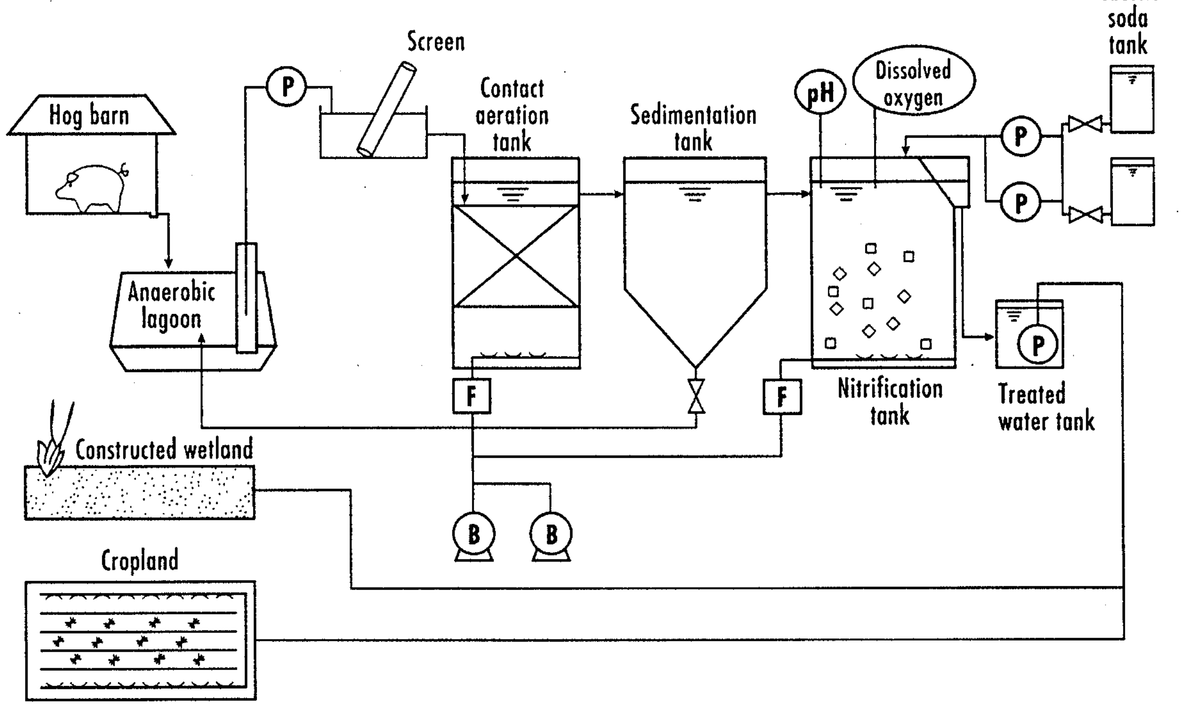
TABLE 1

Batch Treatment of High-ammonia Animal Wastewater with Nitrifying Pellets

Initial Ammonia Concentration mg N/L	Ammonia Removal Rate mg N/ L-reactor/day	Final Nitrate Concentration mg N/L	Efficiency %
344	991	348	100%
860	924	855	99%
1570	917	1525	97%
2608	1013	2569	99%

FIGURE 2

The Pilot-scale Reactor



the nitrification tank. A compressor and fine-air diffusers provided air to the bottom of both tanks. Solenoid valves in the airflow lines responded to dissolved oxygen (DO) concentration to control airflow. Average airflow rates of 50 and 80 L/min were applied to the contact aeration tank and nitrification tank, respectively. These flow rates ensured appropriate fluidization of the pellets and maintained mixed liquor DO concentration at more than 3 mg/L. The nitrification tank pH was maintained between 7.5 and 8.

Effluent from a 4100-m^3 single-stage anaerobic lagoon, which treated and stored manure from 2600 pigs, was used as influent to the pilot reactor. The lagoon liquid contained, on average, 331 mg/L of ammonia and 421 mg/L of total Kjeldahl nitrogen (TKN), but actual concentrations varied markedly throughout the year (see Table 2, below). Most of the variation was attributed to normal growing cycles in the farm operation and not seasonal weather changes, except for COD and BOD increases associated with winter months.

TABLE 2

Swine Lagoon Wastewater Characteristics[1]

	Average	Range
pH	8	7.4 to 8.6
Total Solids	1810	1200 to 4360
Suspended Solids	456	187 to 2790
COD	1107	495 to 3430
BOD	223	61 to 780
TKN	419	270 to 566
Ammonia	331	224 to 461
Nitrate	0	0 to 1
Alkalinity	1846	1460 to 2380

[1]One year data (August 1997 to September 1998) All units mg/L except pH

BOD = Biochemical oxygen demand. COD = Chemical oxygen demand.

TKN = Total Kjeldahl nitrogen.

Acclimating Nitrifying Pellets to Swine Wastewater

Because the pellets were manufactured using activated sludge from a municipal wastewater treatment plant as the nitrifiers, an acclimation procedure was conducted to adapt the nitrifiers for swine wastewater, which contains 10 to 20 times more ammonia than municipal wastewater.

Frequent laboratory tests were conducted to test the pellets' nitrification and oxygen consumption rates. Nitrification activity was determined in 1-L aerated reactors during a 4-hour period using a synthetic medium containing 300 mg/L of ammonia and 10% pellet concentration. The nitrification rate was calculated from the slope of a regression line that related the increase in nitrate concentration and time. Oxygen consumption activity was measured using a DO probe in a closed glass chamber containing 20 mL of pellets and the synthetic medium and calculated from the slope of a regression line that described the decrease of DO in the liquid over time.

During the 3-month acclimation period, flow and ammonia loading rates were increased. The flow rate was increased to the next level when the ammonia concentration of nitrified effluent reached approximately 100 mg/L. At the initial 48-hour HRT, nitrification activity of the pellets increased from 21 to 200 g/m^3·d of nitrogen in about 30 days.

Nitrification activity increased to 319 and 433 g/m^3·d of nitrogen at 32- and 24-hour HRTs, respectively (see Figure 3, right). Activity increased further during the subsequent 3-month period and stabilized between 750 to 900 g/m^3·d of nitrogen in the next 2 years. The pellets' oxygen consumption also increased with time in correlation to nitrification activity. Typically, the pellets consumed 1.5 to 2 g of oxygen per gram of ammonia–nitrogen removed in the laboratory tests.

Nitrification Treatment Performance

After acclimation, the pilot unit was evaluated for 2 years. In the first year (1998), each consecutive run was conducted at a constant HRT and lasted 3 to 4 weeks. The HRT was adjusted by changing the influent flow rate so nitrate production rates could be compared at similar ammonia loading values and different temperatures and optimum nitrification conditions could be deter-

FIGURE 3

Nitrification Activity of Nitrifying Pellets during Acclimation to Swine Wastewater

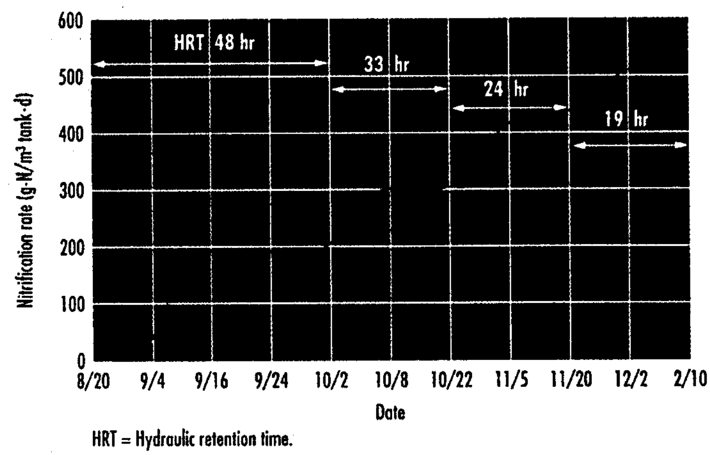


FIGURE 4

Nitrification Performance of Pilot Unit with Varying Nitrogen Loading Rates, First Year (1998)

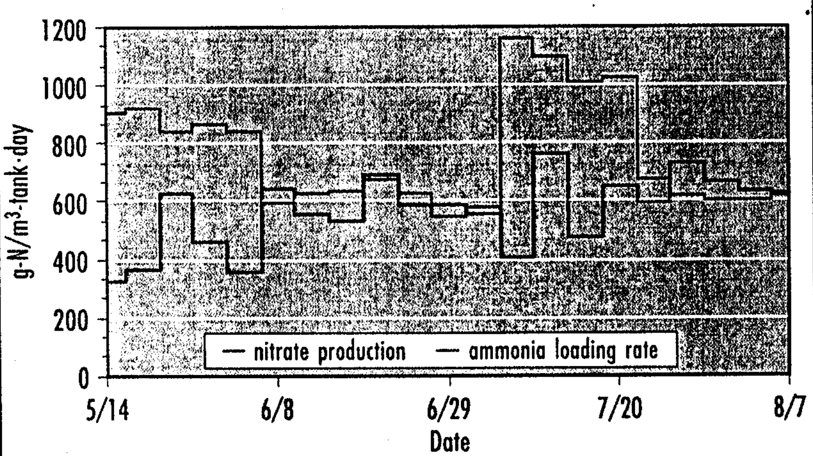


TABLE 3

Treatment of Swine Lagoon Wastewater with Nitrifying Pellets

			Influent Quality			Effluent Quality		
Run No.[1]	Water Temperature	HRT[2]	BOD	Alkalinity	Ammonia	BOD	Alkalinity	Nitrate
	°C	Hours	mg/L Concentration					
	Cold Water Temperature							
2	8.6	33	460	2037	326	277	1514	90
	Mild Water Temperature							
5	19.4	19	128	1896	377	61	337	302
	Warm Water Temperature							
8	29.2	16	210	1931	410	79	333	394

[1] Each run consisted of a 3- to 4-week period at a constant HRT.
[2] HRT = Hydraulic retention time of nitrification tank.
BOD = Biochemical oxygen demand.

TABLE 4

Nitrification Efficiency of Pilot Unit

Run No.[1]	Water Temperature	HRT[2]	Ammonia Loading Rate	Ammonia Removal Rate	Nitrate Production Rate	Ammonia Removal Efficiency	Nitrification Efficiency
	°C	Hours	g N/m³·d			Percent	
	Cold Water Temperature						
2	8.6	33	237	77	65	32	28
	Mild Water Temperature						
5	19.4	19	476	378	381	79	80
	Warm Water Temperature						
8	29.2	16	615	555	590	90	96

[1] Each run consisted of a 3- to 4-week period at a constant HRT.
[2] HRT = Hydraulic retention time of nitrification tank.

TABLE 5

Water Quality of Lagoon Liquid Nitrified by Pellets[1]

	Influent Quality	Effluent Quality	
		Contact Aeration Tank	Nitrification Tank
pH	8.14	8.28	7.67
Alkalinity	1931	1839	333
Suspended solids	460	302	205
COD	898	599	517
BOD	210	108	79
Ammonia	410	404	40
Nitrate	0	4	396
TKN	494	480	88
Total nitrogen	494	484	482

[1] Average data for Run No. 8, June 8 to July 2, 1998; HRT of nitrification tank = 16 hours; ammonia load = 615 mg N/m3·d.
BOD = Biochemical oxygen demand.
COD = Chemical oxygen demand.
TKN = Total Kjeldahl nitrogen.
HRT = Hydraulic retention time.
All units mg/L except pH.

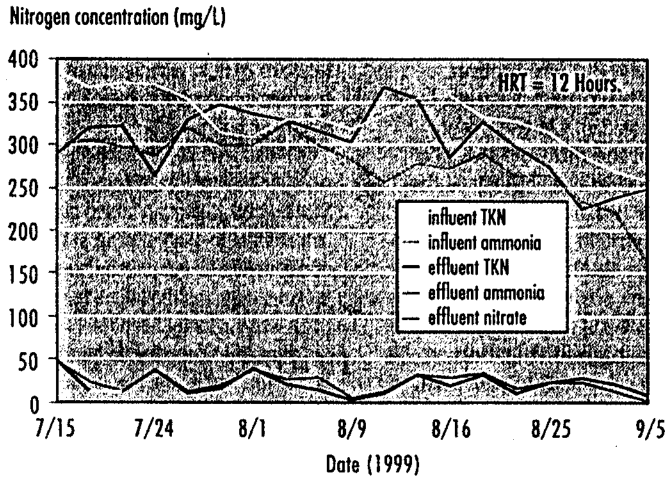
The pilot test indicated that using large populations of nitrifying bacteria entrapped in polymer pellets to nitrify ammonia in animal wastewater is much more effective than conventional activated sludge-based treatment systems.

mined. In the second year of evaluation (1999), the unit was operated at optimum HRT to provide full nitrification treatment.

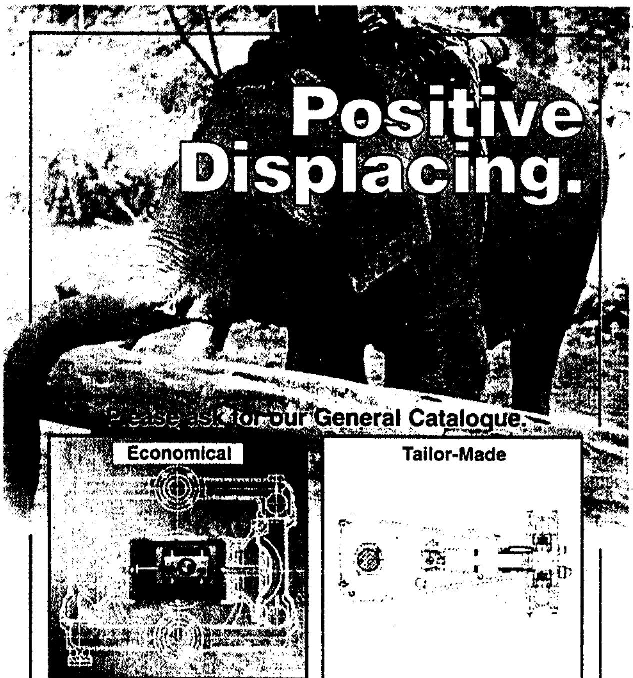
Every 3.5 days, researchers collected 24-hour composite samples from influent, contact aeration tank effluent, and nitrification tank effluent. The samples remained refrigerated at 4°C until chemical analyses were performed

The analyses indicated that seasonal water temperature significantly affected nitrification rates; nitrification rates were low during winter months when water temperatures were lower than 10°C. Not only did low temperatures affect nitrifier activity, they also generated a higher proportion of organic materials in influent wastewater (see Table 3, p. 33). Average nitrate efficiency was 28% (Run No. 2). Pellet activity remained high in laboratory tests conducted with 20°C wastewater in the same winter period (see Figure 3, p. 33). This indicates that high BOD in the winter did not deteriorate the pellets and that nitrification performance may be improved during winter months by adding insulation or external heat.

Nitrate production rates increased significantly at water temperatures greater than 10°C (see Table 4, p. 34). Nitrification efficiencies of more than 80% were obtained during early spring with 476 g of nitrogen per m^3/d ammonia loads and a 19-hour HRT (Run No. 5) and summer with 615 to 626 g of nitrogen per m^3/d ammonia loading and 16- to 12-hour HRTs (runs No. 8 and 10). In all cases, the ammonia–nitrogen removed was converted entirely into nitrate–nitrogen forms without losing ammonia to volatilization. While higher than optimum loadings affected nitrate production and increased variability, using loading rates that matched the pellets' nitrification capacity yielded consistent



HRT = Hydraulic retention time.
TKN = Total Kjeldahl nitrogen.



nitrification performance (see Figure 4, p. 33).

The contact aeration tank reduced organic load effectively. Data for Run No. 8, conducted June 8 through July 2, 1998, at a 16-hour HRT, indicate that 82% of the BOD reduction occurred in the contact aeration tank (see Table 5, p. 35). On the other hand, 99% of the nitrate produced was attributed to the activity of the pellets in the nitrification tank. Although swine lagoon wastewater contains high alkalinity, it usually is not enough to nitrify ammonia completely, and needs to be supplemented to achieve high nitrification.

Excellent nitrification performance also was obtained during the second year of evaluation. Nitrification rates greater than 600 $g/m^3 \cdot d$ were obtained consistently with a 12-hour HRT. Not only did the unit convert all influent ammonia into nitrate, it also converted some organic nitrogen into nitrate (see Figure 5, p. 35).

The pilot test indicated that using large populations of nitrifying bacteria entrapped in polymer pellets to nitrify ammonia in animal wastewater is much more effective than conventional activated sludge-based treatment systems. Immobilized pellets are quick, efficient, and hold tremendous promise for retrofitting existing lagoons.

Although the nitrifying pellets are not yet being used in the United States, the Japanese manufacturer is interested in partnering with U.S. companies to advance the use of the technology to treat animal and other high-strength industrial wastewaters.

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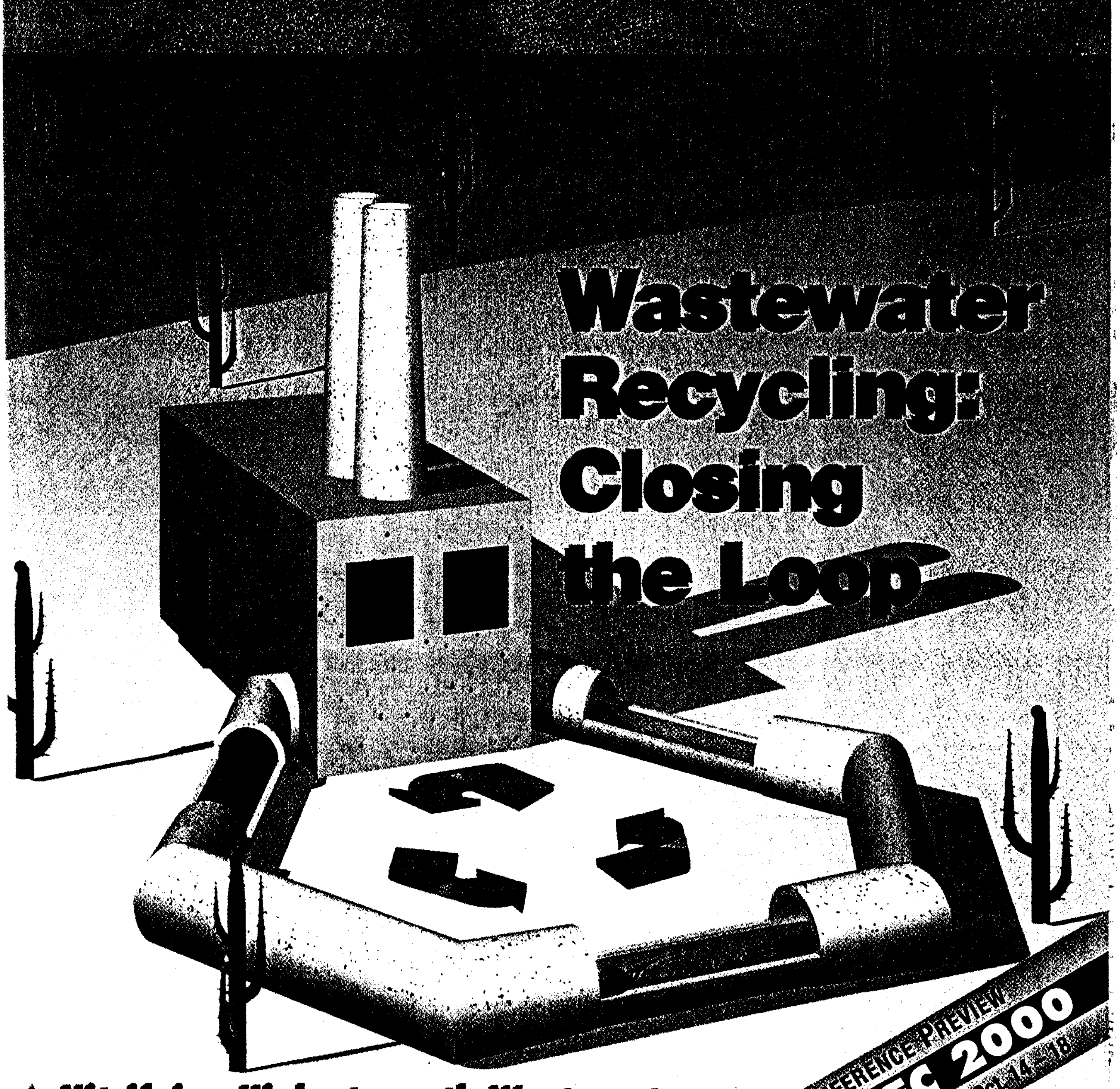

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