United States
Environmental Protection
Agency

Risk Reduction
Engineering Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-88/060 Feb. 1989

EPA

Project Summary

Demonstration and Evaluation of the CAPTOR Process for SewageTreatment

Paul F. Cooper

The sanitary engineering field has demonstrated substantial interest in recent years in the potential benefits of high biomass wastewater treatment. For the most part, this interest has focused on processes that use various forms of support media that have the ability to colonize high concentrations of aerobic bacterial growth. One such concept is the CAPTOR process* developed jointly by the University of Manchester Institute of Science and Technology (UMIST) and Simon-Hartley, Ltd., in the United Kingdom. This high biomass approach uses small reticulated polyurethane pads as the bacterial growth medium. The pads are added to standard activated sludge aeration tankage, and the system is operated without sludge recycle, essentially converting a suspended growth process to a fixed film process. Excess growth is removed from the pads by periodically passing them through specially designed pressure rollers.

The Water Research Centre (WRC) and Severn-Trent Water Authority conducted a full-scale evaluation of the CAPTOR process for uprating the activated sludge plant at the Freehold Sewage Treatment Works (near Stourbridge in the West Midlands area of England) to achieve year-round nitrification. The process suffered initially from several major design and operational problems. The report describes how resolution of these problems was achieved in pilot-scale studies at the WRC's Stevenage Laboratory before implementing the design and operating changes so determined on the two full-scale CAPTOR trains at Freehold.

Whereas the pilot-scale studies were successful in providing solutions to basic design and operational flaws, they were not able to develop techniques for improving CAPTOR process effluent quality. CAPTOR performance was adversely affected throughout the project by high levels of suspended solids in the process effluent in both pilot- and field-scale studies. These high solids levels prevented the uprated system at Freehold from achieving nitrification.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use

Introduction

The CAPTOR process originated from research work on pure systems in the Chemical Engineering Department of UMIST. Single strands of stainless steel wire were woven into a knitted formation and then crushed into a sphere of about 6 mm (0.25 in.) diameter. These particles of known surface area were used for modeling liquid-fluidized bed systems. From this work derived the idea of using porous support pads for growing biomass at high concentrations that could be used in wastewater treatment systems. The idea was jointly developed and patented by UMIST and their industrial partner Simon-Hartley, Ltd. The present form of the CAPTOR process uses 25 mm x 25 mm x 12 mm (1 in. x 1 in. x 0.5 in.) reticulated polyether foam pads containing pores nominally of about 0.5 to 0.9 mm (0.02 to 0.035 in.) diameter and 94% free space.

Simon-Hartley, Ltd. conducted pilot-plant work that indicated it was possible to achieve

- biomass concentrations of 7,000 to 10,000 mg/L,
- waste sludge concentrations of 4% to 6% dry solids using a special pad cleaner,
- improved oxygen transfer efficiencies, and
- high BOD volumetric removal rates

In 1982, WRC and Severn-Trent Water Authority agreed to jointly evaluate the CAPTOR process at the Freehold Sewage Treatment Works near Stourbridge, West Midlands. The Freehold plant did not achieve any nitrification in the winter and only partial nitrification in the summer. Freehold's activated sludge system consisted of five trains equipped with tapered fine bubble dome diffusers arranged in a grid (floor coverage) configuration. The system was modified as shown in Figure 1 to split the wastewater flow into two equal volumes. Half went to two trains that were modified by adding CAPTOR pads to the first quarter of two aeration basins, and the other half went to two trains that remained unaltered and served as a control The CAPTOR modified trains were each equipped with a CAPTOR pad cleaner (Figure 2), and the CAPTOR pads were prevented from escaping into the remainder of the experimental system aeration basins by screens placed at the effluent ends of the CAPTOR zones.

The Simon-Hartley design predicted that, with a concentration of 40 pads/L, an annual average removal of 75% of the BOD_5 coming into the plant could be achieved in the CAPTOR zones, resulting in a reduced food-to-microorganism (F/M) loading on the follow-on activated sludge stage of 0.08 kg BOD_5/day/kg MLSS. With the reduced load, it was predicted that the modified system would achieve year-round nitrification with an effluent ammonia nitrogen concentration of 5 mg/L or less.

Full-Scale Plant Initial Results

The Freehold modified CAPTOR/activated sludge system was put in operation in September 1982 and immediately encountered a major pro lem. The CAPTOR pads floated on tl surface of the tanks and would n become incorporated into the tank liqu A solution was found in November wh three of the seven longitudinal rows fine bubble diffusers in the CAPTC aeration basins were removed. This w done to create a spiral roll in the tan

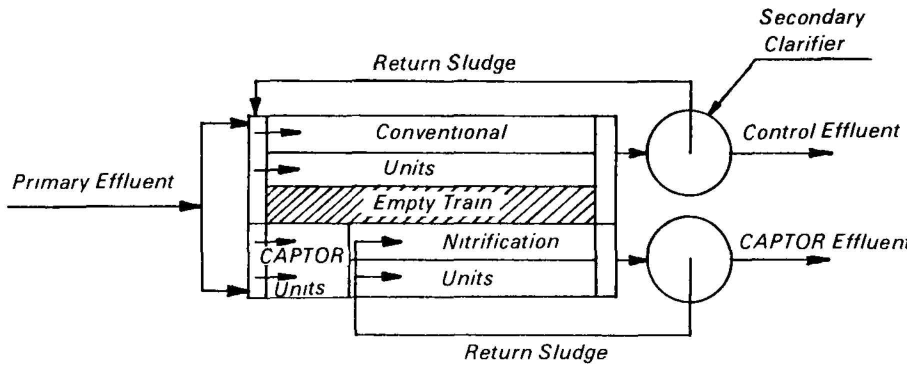

Figure 1. Schematic of Freehold Sewage Treatment Works showing incorporation of CAPTOR/nitrification trains

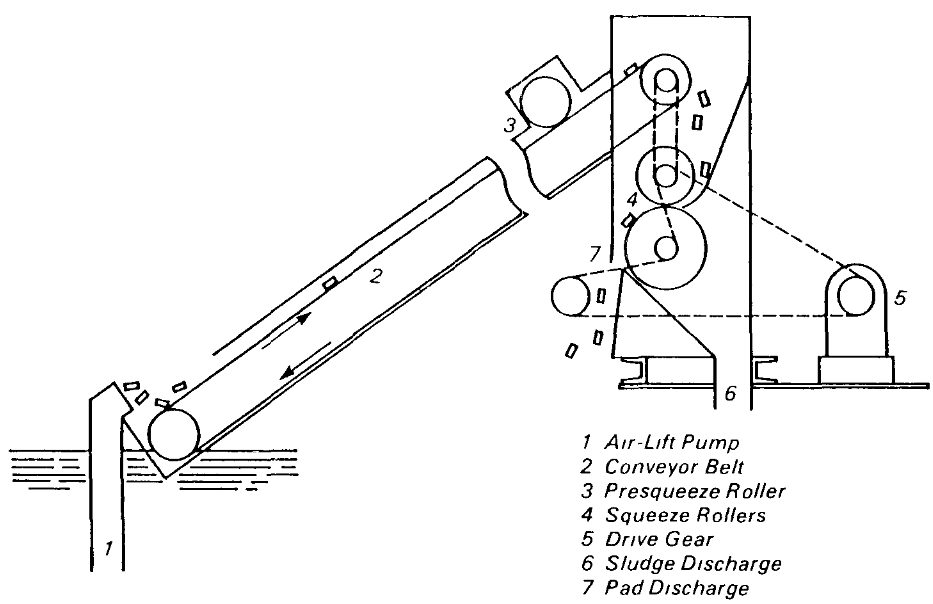

Figure 2. Diagram of CAPTOR pad cleaner

because it was known that coarse bubble diffusers had been used in the previous work done by Simon-Hartley. Coarse bubble diffusion leads to areas of rising and falling liquid with quite large channels down which the pads can fall. In the existing fine bubble grid system, the falling zones were much smaller and did not allow the pads to fall and then recirculate. The spiral roll modification provided the necessary falling zone and produced complete mixing of the CAPTOR pads.

Another problem that occurred at this time was maldistribution of the pads. The flow of wastewater tended to push the CAPTOR pads to the outlet of their zones, resulting in concentrations of the order of 50 to 60 pads/L at that end and only 10 to 20 pads/L at the inlet end.

One other disturbing feature was the rapid deterioration in the CAPTOR pads. The CAPTOR pads used initially were black and were wearing at such a rate that they would not have lasted for more than 3 yr (making the process non-economic).

It had also become evident by this time that with the Freehold wastewater it would be possible to achieve the concentration of 200 mg biomass/pad predicted by Simon-Hartley. However, it was found that if the biomass was allowed to grow beyond 180 mg/pad, the biomass in the center of the pad became anaerobic. The control of pad biomass was difficult because the pad cleaners provided were not reliable and were situated at the CAPTOR zone inlets while most of the pads gravitated to the outlet ends of the zones.

During the period November 1982 to May 1983, while the above problems were being tackled on the full-scale plant, there were some occasions when the effluent from the CAPTOR units was reasonable (BOD_5 removals of 40% to 50%), but BOD_5 removal never approached the average of 75% predicted by Simon-Hartley based on their pilot-plant results. Poor BOD_5 removals were being experienced because the suspended solids concentration in the effluent was always high (>80 mg/L). Operating conditions and performance results for these early runs are summarized in Tables 1 and 2, respectively.

By July 1983, it was obvious that the CAPTOR process was not sufficiently developed for the Freehold project to be regarded as just an evaluation. A change was then made from an evaluation to a development project wherein pilot-scale studies would be used to find solutions to the operating problems described above before attempting further full-scale evaluation at Freehold. Simon-Hartley became partners, and funding was obtained from the Department of Trade and Industry. Each of the partners contributed 25% of the overall costs.

Table 1. *Initial Freehold Operating Conditions*

Period	Wastewater Flow/Train (mgd)	First-Stage CAPTOR HRT (min)	Second-Stage Activated Sludge System HRT (min)
11/22 – 12/31/82	1.50	43	127
6/1 – 7/7/83	1.38	48	137
9/15 – 11/4/83	1.35	47	143

Table 2. *Initial Freehold Performance Results*

Parameter (mg/L)	Primary Effluent	Experimental System: CAPTOR Zone Effluent	Experimental System: Final Effluent	Control System Effluent
11/22 - 12/31/82				
BOD_5	114.	45.	13.	19.
SS	101.	81.	19.	25.
NH_4-N	22.1	18.2	23.5	24.4
Oxidized-N	-	-	2.2	3.3
6/1/-7/7/83				
BOD_5	142.	78.	10.	22.
SS	122.	90.	14.	29.
NH_4-N	26.3	20.2	24.9	24.9
Oxidized-N	-	0.5	3.2	2.7
9/15-11/4/83				
BOD_5	136.	78.	12.	15.
SS	144.	104	17	23.
NH_4-N	26.4	20.6	6.1	6.0
Oxidized-N	-	2.0	12.2	11 6

Development Project (Pilot-Scale Studies)

The development project began with two levels of pilot-scale studies carried out at the WRC Stevenage Laboratory:

1. Initially, small tanks (265 L = 70 gal) were utilized to characterize CAPTOR process performance under very controlled conditions.
2. This was followed by larger-scale tests in a hydraulic test rig (HTR), volume = 30 m^3 (7,930 gal), where various inlet and outlet arrangements, aeration patterns, and cleaning rates could be assessed under near full-scale plant conditions.

The results of the small-tank and HTR studies were to be used in deciding what modifications could be implemented on the full-scale plant at Freehold. The governing principle was that no major modification could be made on the full-scale plant until it had first been assessed on the HTR.

At this time, it was also decided to evaluate two variations of the CAPTOR process. Linde AG of West Germany was testing a process similar to CAPTOR called the LINPOR process. LINPOR differed from CAPTOR in that sponge pads were placed directly into the mixed liquor of an activated sludge aeration tank rather than in a separate stage before the activated sludge tank. It was decided to test this process variation using CAPTOR pads rather than LINPOR pads in the 265-L (70-gal) tank arrangement at

Stevenage. WRC named this process variation CAST (CAPTOR in activated sludge treatment). A control activated sludge pilot unit was operated in parallel with the CAST unit.

In addition, a single aeration tank, volume = 236 L (62 gal), filled with 40 CAPTOR pads/L, was fed effluent from the above activated sludge control unit to assess the potential of CAPTOR as a second-stage nitrification process. Neither pad cleaning nor final clarification was necessary with this process variation because of the low sludge yields characteristic of nitrifier growth

Small-Tank Results

These studies were conducted using two well-mixed CAPTOR tanks in series. A range of loading and pad cleaning rates were used to evaluate process removal capabilities for CAPTOR. The intermediate effluent was used as a measure of process efficiency of the primary reactor and the final effluent for the entire system. This permitted plotting (Figure 3) of % BOD_5 removal (total and soluble) vs volumetric organic loading rate over the range of 1 to 3.5 kg BOD_5/day/m^3 (62 to 218 lb/day/1,000 ft^3). High and low pad cleaning rates are differentiated in Figure 3 as ≥16% and <16% of the total pad inventory/day, respectively.

Total BOD_5 removal efficiency was less than soluble BOD_5 removal efficiency because of the oxygen demand exerted by the biomass solids lost in the process effluent. The higher pad cleaning rates are believed to have contributed to the improved total and soluble BOD_5 removals shown in Figure 3, although low bulk liquid DO's may have adversely affected removals on some of the low cleaning runs. Low cleaning rates (<16%/day) were detrimental to soluble BOD_5 removal efficiency because of a gradual decline in activity of the biomass remaining in the pad. Cleaning rates greater than 24%/day, however, resulted in reduced biomass levels in the pads and a reduction in performance.

HTR Results

The problem of maldistribution of CAPTOR pads in the aeration tank (i.e., crowding of pads into the effluent end of the tank when operated in plug flow fashion as at Freehold) was solved in the HTR by modifying the flow pattern to transverse flow (across the width of the tank rather than down the length). When implemented later at Freehold, this

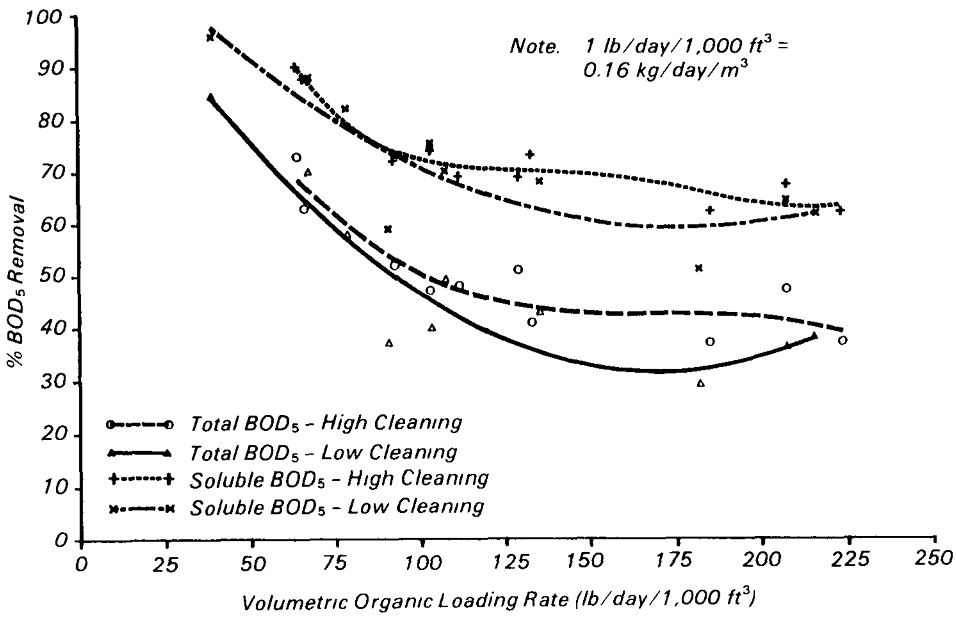

Figure 3. Small tank CAPTOR total and soluble BOD_5 removals at high and low pad cleaning rates

Table 3. HTR Operating Conditions and Process Performance

Parameter	Period 10/8–12/7/84		12/12/84–2/21/85	
Volumetric loading (lb BOD_5/day/1,000 ft^3)*	113		213	
HRT (hr)	2 32		1.52	
Pads/L	40		40	
Biomass/pad (mg)	121		126	
Equivalent MLSS (mg/L)	4,840		5,040	
F/M loading (kg BOD_5/day/kgMLSS)	0.37		0.68	
SRT (days)	3 23		1 72	
DO (mg/L)	4.2		4.7	
	In	Out	In	Out
Total BOD_5 (mg/L)	175	93	216	129
Soluble BOD_5 (mg/L)	86	24	85	33
SS (mg/L)	116	120	178	160
Total BOD_5 removal (%)	47		40	
Soluble BOD_5 removal (%)	72		61	
SS removal (%)	- 3		10	

*1 lb/day/1,000 ft^3 = 0.016 kg/day/m^3

pattern resulted in a fourfold decrease in flow velocity.

Several mixing intensities and diffuser arrangements were tried to decrease biomass shedding into the process effluent. It became obvious, however, that production of effluent biomass solids was not significantly affected by changes in mixing intensity or diffuser arrangement. High effluent suspended solids proved to be far more dependent on pad cleaning rate, biochemical activity of the biomass, and biomass growth directly [in] the liquor.

Using the transverse flow scheme a[nd] a regular pad cleaning regimen, HT[R] CAPTOR process performance w[as] similar to that experienced in the sm[all] tanks. Operating parameters and proce[ss] performance are summarized in Table [3] for two different volumetric loading rate[s].

Respiration studies conducted usi[ng] pads taken from the HTR indicated th[at] biomass held within the pads respires

Table 4. *Operating Conditions and Performance Results – CAST vs Activated Sludge*

Parameter	System			
	CAST		Activated Sludge	
Volumetric loading (lb BOD_5/day/1,000 ft^3)*	148		148	
HRT (hr)	1.8		1.8	
Pads/L	34		–	
Biomass/pad (mg)	116		–	
Equivalent MLSS in pads (mg/L)	3,930		–	
MLSS in suspension (mg/L)	3,720		6,030	
Total MLSS (mg/L)	7,650		6,030	
F/M loading (kg BOD_5/day/kg total MLSS)	0 31		0 39	
SRT, based on total MLSS (days)	3.6		3.0	
DO (mg/L)	2 5		3.0	
	In	Out	In	Out
Total BOD_5 (mg/L)	178	12	178	20
Soluble BOD_5 (mg/L)	101	5	101	4
SS (mg/L)	121	15	121	23
Total BOD_5 removal (%)	93		89	
Soluble BOD_5 removal (%)	95		96	
SS removal (%)	88		81	

*1 lb/day/1,000 ft^3 = 0.016 kg/day/m^3

up to 40% to 50% less than equivalent biomass in free suspension. Any increase in net biomass concentration achieved in a CAPTOR reactor above that in a conventional activated sludge reactor may not produce noticeable benefits, therefore, due to the lower specific activity. These observations suggest that diffusion limitations were occurring in the CAPTOR pads.

CAST Results

The CAST variation of CAPTOR was operated in conjunction with a final clarifier to settle the mixed liquor solids component of the total biomass inventory and return it to the aeration tank. CAPTOR pads and biomass retained therein were kept in the reactor by screens. Operating and performance data are compared in Table 4 for the CAST unit and the parallel activated sludge control unit for a 25-day period (November 5-30, 1984) when the volumetric loadings and hydraulic residence times (HRT's) for both units were identical.

Nitrification Results

Small-tank nitrification experiments were conducted on the CAPTOR process from November 1984 to February 1985. Biomass concentrations per pad ranged from 99 to 124 mg. With a pad concentration of 40/L, equivalent MLSS levels varied from 3,960 to 4,960 mg/L. Liquor DO concentrations were maintained between 6.4 and 8.4 mg/L, and liquor temperature ranged from 11.5° to 6.5°C.

Secondary effluent from the control activated sludge pilot unit used in the CAST experiments was applied to the nitrification reactor over a range of loading conditions. These loading conditions and corresponding performance data are summarized in Table 5. Essentially complete nitrification was achieved at TKN and ammonia nitrogen loadings of approximately 0.25 kg/day/m^3 (15.6 lb/day/1,000 ft^3) and 0.20 kg/day/m^3 (12.5 lb/day/1,000 ft^3), respectively.

Full-Scale Plant Results after Modifications

Following the successful testing of the transverse mixing arrangement in the HTR at Stevenage, the two Freehold CAPTOR trains were modified. Modifications commenced in November 1984 and were completed in mid-March 1985.

Table 5. *CAPTOR Nitrification Operating Conditions and Performance Data*

Parameter	11/08/84-11/28/84	12/03/84-12/20/84	1/03/85-1/18/85	1/21/85-2/08/85	2/11/85-2/15/85
HRT (hr)	1.9	4 6	4.2	4 0	2.7
TKN loading (lb/day/1,000 ft^3)*	36.2	15 0	20.6	16 2	28.7
NH_4-N loading (lb/day/1,000 ft^3)*	30.6	12 5	16.9	13.1	20.6
Total BOD_5 in (mg/L)	21.	23.	52.	13	22.
Total BOD_5 out (mg/L)	21.	19.	44.	17.	16.
SS in (mg/L)	22.	27.	53.	21.	39.
SS out (mg/L)	14.	22.	52.	26.	16.
TKN in (mg/L)	46.	46.	57.	43.	51.
TKN out (mg/L)	28.	10.	38.	6.	15
TKN removal (%)	39	78.	33.	86.	71.
NH_4-N in (mg/L)	39.	36.	44.	35.	37
NH_4-N out (mg/L)	23.	6.	29	3	12
NH_4-N removal (%)	41.	83.	34.	94	68
NO_3-N out (mg/L)	5.	29	13	36	32

*1 lb/day/1,000 ft^3 = 0.016 kg/day/m^3

The modifications involved

- splitting each of the CAPTOR trains, C1 and C2, into two compartments, C1A and C1B and C2A and C2B, as shown in Figure 4;
- feeding influent flow along long weirs at the side of the trains instead of at the narrow inlet ends;
- modifying the aeration pipework to place all three rows of dome diffusers directly below the outlet screens (covering about 25% of the width of the tanks), thereby creating a spiral roll of pads and liquid counter-current to the flow of wastewater entering along the weirs on the sidewalls;
- installing two extra pad cleaners so that each CAPTOR sub-unit was provided with a cleaner; and
- installing fine screens at the outlet from the primary clarifiers to reduce the quantity of floating plastic material entering the CAPTOR units that created problems with the cleaners

The objective of the first three modifications was to achieve uniform mixing of the pads in the CAPTOR units and prevent the situation that had occurred previously where high concentrations of pads (50 to 60 pads/L) collected at the outlet end and very low concentrations (10 to 20 pads/L) at the inlet end. Pads were removed from the tanks during the modifications. After the modifications were completed, the number of pads in each compartment was equalized at about 35/L.

The changes were completely successful in obtaining uniform distribution and complete mixing in of the CAPTOR pads. A lithium chloride tracer test conducted on the modified tanks indicated that no dead zone was occurring in the "eye" of the roll. Formation of floating pad rafts (which had occurred at the outlet end of the tank with the original arrangement) was completely eliminated. The modifications, however, had no effect on the high level of suspended solids present in the liquor.

The performance of the modified CAPTOR system and the parallel activated sludge train was monitored from April 1 to July 23, 1985. The average volumetric loading rate to each train was 1.24 kg BOD_5/day/m^3 (77 lb/day/1,000 ft^3), and the average HRT in each train (excluding sludge recycle) was 2.55 hr. The results of these tests are presented in Table 6.

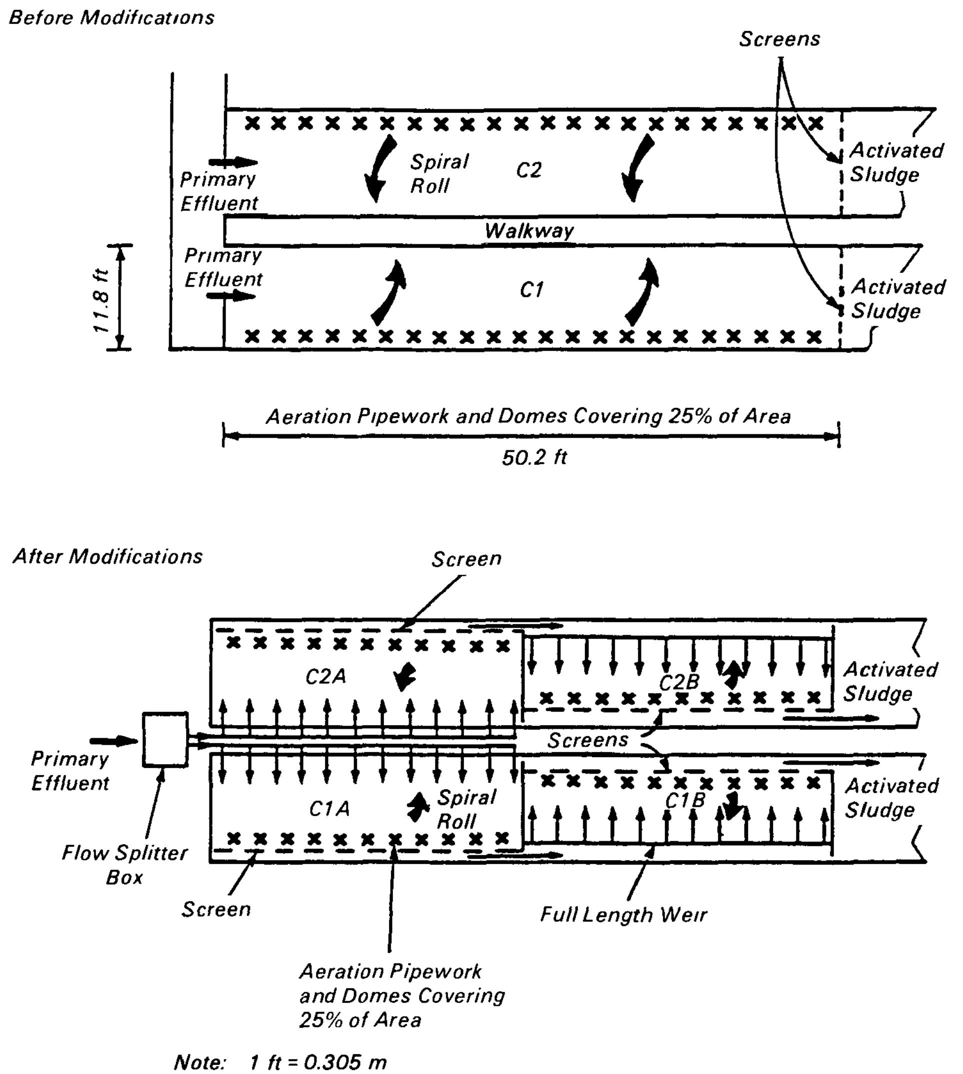

Figure 4. *Modifications to Freehold CAPTOR system flow pattern.*

Clearly, the modified CAPTOR unit was less effective in removing BOD and suspended solids than the parallel control activated sludge system at the same volumetric loading rate, despite the fact that it carried a higher overall biomass concentration (4,830 vs 2,623 mg/L). The interstage values in Table 6 show that the CAPTOR portion of the modified trains had higher effluent suspended solids levels than the primary effluent.

Throughout the experiments, problems were encountered in keeping all the CAPTOR pad cleaners in operation. The Mark II pad cleaners developed by Simon-Hartley were an improvement on the Mark I units, but still suffered from blockages and breakdowns.

The CAST variation of the CAPTO process, which had exhibited somewh better performance than convention activated sludge in the small tar experiments, was also field evaluated Freehold. The CAPTOR trains wel further modified so that return sludg could be introduced to the CAPTO zones (35 pads/L), providing an activate sludge component throughout the entii aeration tanks, not just in the nitrificatic stage. CAPTOR pads were not added the nitrification stages as this would ha\ required substantial additional tar modifications.

The full-scale CAST system wa operated in parallel with the activate sludge control trains from August 1 October 31, 1986. The averag volumetric organic loadings and HRT's (excluding sludge recycle) for each system were 1.11 kg BOD_5/day/m^3 (69 lb/day/1,000 ft^3) and 3.40 hr, respectively.

Performance data summarized in Table 7 indicate that, contrary to the small tank results, the CAST system effluent was of poorer quality than that of the conventional activated sludge system. In addition, difficulties were experienced in supplying sufficient air to the CAPTOR units. The maximum air supply had been sized for the CAPTOR pads alone, and this was not enough at times to satisfy the oxygen demand created by the biomass on the pads and the biomass of the mixed liquor.

Table 6. *Full-Scale Performance Results – Modified CAPTOR Activated Sludge System vs Conventional Activated Sludge*

Parameter (mg/L)	Primary Effluent	Experimental System: CAPTOR Zone Effluent (C2A & C2B)	Experimental System: Final Effluent	Control System Effluent
Total BOD_5	128.	122.	22.	16.
Soluble BOD_5	40.	28.	4.	3.
SS	138.	154.	32.	23.
NH_4-N	24.0	24.9	24.4	22.5
Oxidized-N	–	–	0.6	2.0

Table 7. *Full-Scale Performance Results – CAST vs. Conventional Activated Sludge*

Parameter (mg/L)	Primary Effluent	CAST System Effluent	Control System Effluent
Total BOD_5	138.	16.	10.
Soluble BOD_5	56.	2	2
SS	120.	27.	15.
NH_4-N	26.7	17.2	11.4
Oxidized-N	–	3.7	7.8

Conclusions

1. When the CAPTOR process was installed at the Freehold Sewage Treatment Works, several problems were immediately evident:

   a. There were major problems with respect to pad mixing, suspension, and distribution.

   b. The Mark I pad cleaners were not reliable.

   c. Performance was adversely affected by the high level of suspended solids in the CAPTOR stage effluent.

   The problems of pad mixing and distribution were solved by pilot- and full-scale development work. The Mark II pad cleaners produced by Simon-Hartley were a considerable improvement over the Mark I cleaners, but minor problems remained to be resolved.

2. The performance of the CAPTOR process was still adversely affected by the high level of suspended solids in the CAPTOR stage effluent after correction of the pad mixing, suspension, and distribution problems. This prevented the achievement of nitrification in the follow-on activated sludge stage.

3. The presence of CAPTOR pads in the tank liquid did not improve oxygen transfer efficiency.

4. The durability of the CAPTOR pads was solved by switching to different pads. The original black pads (made by ScotFoam, Inc., USA) deteriorated rapidly as did the yellow CAPTOR pads provided by Recticel (Belgium), but the orange pads made by ScotFoam, Inc., were very durable.

5. The peak biomass concentration in the pads is unpredictable. It does not appear to be related to the BOD concentration of the wastewater. There were indications in the various studies, however, that the frequency of pad cleaning (and, hence, the biomass/pad concentration) was critical to the performance of the process. Regular pad cleaning is essential to prevent anaerobic conditions from developing in the pads.

6. It is possible to raise the biomass concentration in a CAPTOR stage to 6,000 to 8,000 mg/L, but the respiration rate of the biomass in the pads is lower than the respiration of the same biomass if freely suspended and less than that of normal activated sludge. These data suggest that the geometry of the CAPTOR pads results in diffusion limitations, which severely restrict the potential for economic utilization of the CAPTOR process in wastewater treatment.

7. The CAST variation of the CAPTOR process performs well, but it is doubtful if it is economic.

8. CAPTOR may have some potential as an add-on package for tertiary nitrification. However, this process variation may not be cost competitive.

9. The use of CAPTOR as a roughing treatment (followed by interstage clarification) was estimated to be less cost effective than using conventional nitrifying biological filters for uprating Freehold to complete year-round nitrification. The CAPTOR option, however, was projected to be more cost effective than extending the activated sludge plant for the same purpose.

The full report was submitted in fulfillment of Cooperative Agreement No. CR810911 by the Water Research Centre of Stevenage, England, under the partial sponsorship of the U.S. Environmental Protection Agency.

Paul F. Cooper is with the Water Research Centre, Stevenage, Hertsfordshire SG1 1TH, United Kingdom.
***Richard C. Brenner** is the EPA Project Officer (see below).*
The complete report, entitled "Demonstration and Evaluation of the CAPTOR Process for Sewage Treatment," (Order No. PB 89-118 665/AS; Cost: $21.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use $300

EPA/600/S2-88/060