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EVALUATION OF THE ANFLOW PROCESS

May 1980

Work Performed Under Contract No. AC01-79PE70048

JBF Scientific Corporation
Wilmington, Massachusetts

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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Division of Industrial Energy Conservation

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EVALUATION OF THE
ANFLOW PROCESS

By

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For

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I. INTRODUCTION AND OVERVIEW OF SYSTEMS

Since 1974, the Chemical Technology Division at Oak Ridge National Laboratory (ORNL) has been investigating an anaerobic process for wastewater treatment. The process is designed to remove suspended solids and oxygen-demanding organics. In this process, wastewater flows upward through a column that contains a solid packing material supporting microorganisms. ORNL has termed the process ANFLOW (ANaerobic upFLOW).

Initially, the test columns at ORNL were inoculated with cultures from bovine ruminant fluids. Hence, another term that has been applied to the ANFLOW columns is "ruminant bioreactors", although the ORNL investigators prefer the term ANFLOW. Some columns have been started successfully with inocula from other ANFLOW columns rather than with ruminant fluids.

ANFLOW columns have been tested at bench scale and in a 5,000-gallon per day pilot plant treating domestic wastewater. The process is designed to remove solids and oxygen-demanding substances in one step, requiring no aeration, and generating very little sludge. Because aeration and sludge handling are energy-intensive aspects of conventional wastewater treatment processes (e.g. activated sludge), the ANFLOW process has the potential to reduce energy consumption in wastewater treatment plants. Moreover, because the process is anaerobic, it can generate methane. Use of this methane as a fuel within treatment plants or elsewhere merits technical and economic assessment.

A. PURPOSE

The purpose of this report is to provide the Department of Energy's Office of Policy and Evaluation with a technical and economic assessment of the ANFLOW process. Specific items addressed to achieve this purpose include:

- Whether the primary energy-related advantage is energy conservation or energy production (i.e. methane);
- Total annual energy production/saving potential if ANFLOW achieved 100 percent penetration of its total market;
- State of technical development;
- Likely deployment characteristics (large central or small dispersed plants);
- Present and future economic competitiveness;
- Identification of unique/proprietary concepts.

These items, as well as others that emerged during the investigation, are assessed in Sections III and IV.

B. PROCESS DESCRIPTION

1. Physical Arrangement

ANFLOW units may vary in size, but their physical configuration has always been as shown in Figure 1. The principal units that have been tested to date have the following dimensions:

1. Bench scale: 1.5 in. diameter, 3 ft. high

2. Larger bench scale: 9 in. diameter, 6 ft. high

3. Pilot plant: 5 ft. diameter, 18.3 ft. high

Rectangular geometries may be tested in the future. Details of design and operation are provided in later sections of this report. Some of the major factors to keep in mind with regard to Figure 1 are:

1. Effective gas collection requires that the column be well sealed.

2. Hydraulic factors in design and operation are crucial to success. The influent flow must be fed evenly into the bottom of the packed section; plug flow without "short circuiting" should be maintained; and flow rates should be low enough to provide required residence time and avoid washout of solids.

2. Biological Factors

ANFLOW columns have always been started up by inoculating with cultures from bovine ruminant fluids, or from operating ANFLOW columns. Ruminant fluids contain a unique anaerobic microbial assemblage consisting of organisms that can break down cellulose, methane formers, and protozoans that graze on bacteria (thus keeping down the mass of microbial cells).

Little microbiological work has been done at ORNL to follow the behavior and composition of the microbial community within the ANFLOW columns. Other inocula have not been used. Therefore, no data are available for assessing the need for or benefits from the use of ruminant fluids, although ORNL doubts that these fluids are an essential inoculum.

C. IMPORTANT WASTEWATER PARAMETERS

The principal regulated parameters in wastewater discharges from publicly owned treatment works (POTW's) are suspended solids and biochemical oxygen demand (BOD). BOD is an indication, based on a laboratory test, of the rate at which aerobic microorganisms consume oxygen while metabolizing organic matter in the water. This parameter, therefore, gives insight into a wastewater's potential to deplete oxygen in receiving waters. BOD is customarily determined by measuring oxygen depletion in a sample that has been incubated for five days (BOD_5). Organic matter can also be measured more quickly by other methods, yielding values for parameters such as chemical oxygen demand (COD) and total organic carbon (TOC). TOC in particular was frequently used by ORNL in developing operating data with ANFLOW columns. For

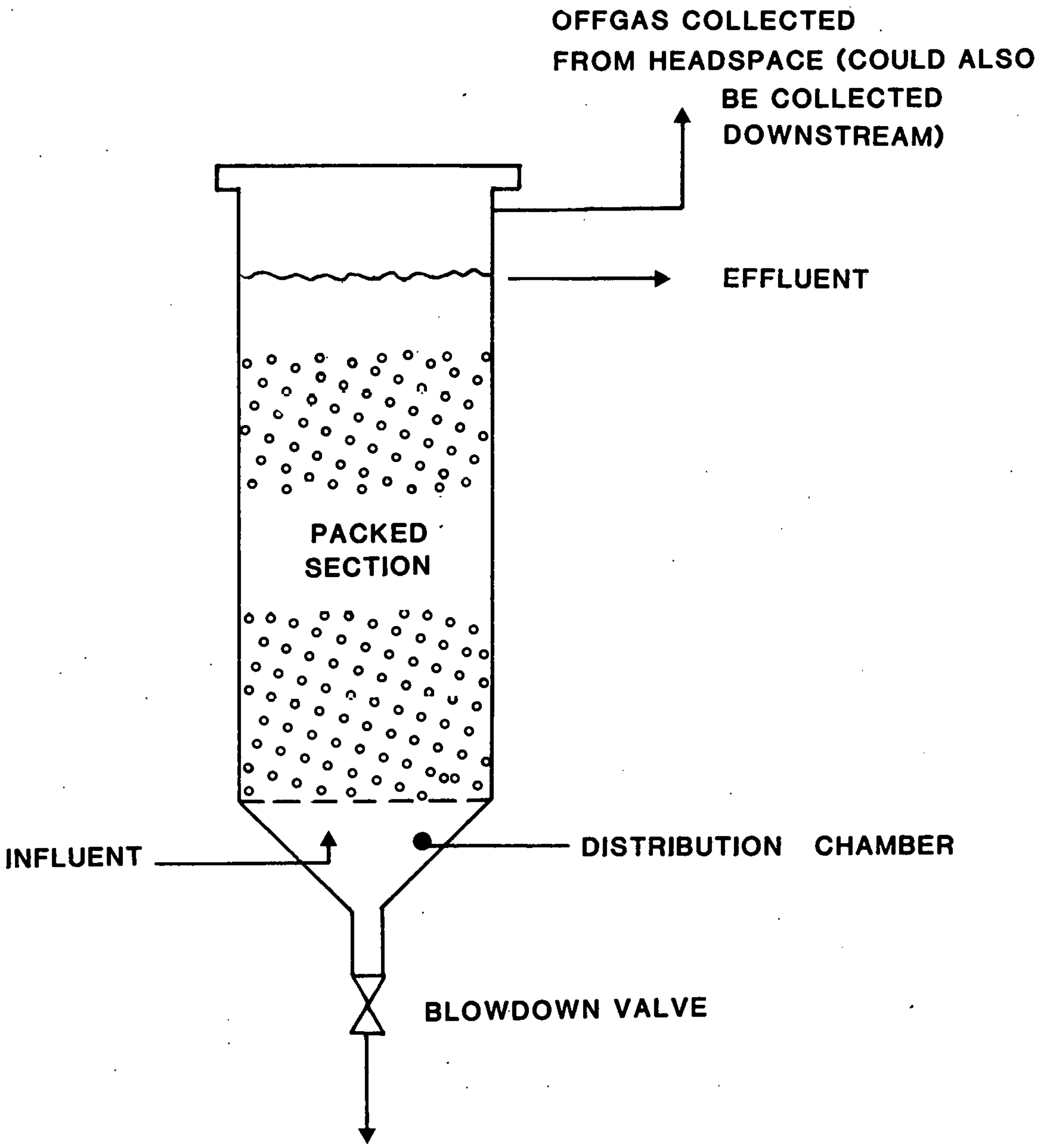

Figure 1. Schematic of an ANFLOW Column

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municipal wastewaters, TOC and BOD_5 will normally be strongly correlated, so that discussions in this report of TOC removal should, in general, be applicable to BOD removal as well. For the specific question of meeting standards on BOD_5, however, only data on BOD_5 are applicable.

II. SUMMARY, FINDINGS, AND CONCLUSIONS

This report analyzes the ANFLOW process being developed at Oak Ridge National Laboratory for treatment of organic wastewaters. The process is compared to conventional treatment processes on the basis of environmental effects, energy use, methane production, and cost. As the analyses progressed, several assumptions were required because tests on the process have been at small scale and have observed a limited number of parameters.

The ANFLOW process, with granular media filtration of the effluent, appears able to meet standards for secondary treatment of most municipal wastewaters. If further demonstrations can show reliability under a range of influent conditions, if ammonia levels in the discharge can be controlled, and if bioassays show that the effluent's toxicity is not higher than that of conventional effluents, then environmental contraints should not impede commercialization of the process. The required demonstrations and process refinements should require 5 to 10 years, if the design flow is increased tenfold every three years. Faster commercialization is possible, but at higher risk that unforeseen problems might occur in full-scale systems.

Energy consumption of the ANFLOW process is much less than that of activated sludge systems. Comparisons with trickling filter systems are also favorable, but by a smaller margin.

Use of methane generated in ANFLOW reactors may be hindered by several factors that have been given little attention in previous reports on the process:

- Under the test conditions used to date, nearly half of the methane produced is dissolved in the reactor effluent. Recovery of this methane for use as a fuel is not a trivial matter. Production of gaseous methane would be enhanced by treating stronger wastes or by reactor operation at higher temperature.

- Methane yields appear to be limited by the fact that significant amounts of organic material accumulate within the reactor without being biochemically converted.

- Small treatment plants, which may select the ANFLOW process for its simplicity, may forego methane use because gas collection and storage systems require operator attention.

Another factor in methane generation is the waste strength. For dilute influents (e.g. 100 mg/ℓ, as at the Oak Ridge East Treatment plant), ANFLOW energy requirements are greater than the energy available from the produced methane. Thus, ANFLOW is an energy-saving process at all flow ranges and waste strengths, but produces surplus energy only under some conditions. Those conditions depend on future availability of small-scale equipment to collect, store, and use reactor offgas. Based on assumptions defined in this report, plants larger than 0.5 mgd treating wastes stronger than 100 mg/ℓ BOD_5 should, in the future, produce surplus offgas with potential for offsite use.

Costs for ANFLOW-based treatment systems appear to be lower than those for conventional systems at design flows up to approximately 1 mgd. Larger plants are difficult to assess because information about ANFLOW is lacking. Larger-scale demonstrations of the process will aid future assessments for larger plants.

A series of alternate sets of assumptions about future market penetration has led to national projections for the year 2000 of potential energy benefits from the use of ANFLOW. If all new construction of publicly-owned treatment works beginning immediately were designed around ANFLOW, the national annual energy benefit (conservation plus methane production) relative to activated sludge would be 0.006 quads. Relative to trickling filters, the value would be 0.003 quads. These are highly speculative figures, necessarily based on many assumptions. In reality, the commitment cannot be made until several more years of process development have occurred. These values are, therefore, more appropriate to the year 2010. (They were estimated for the year 2000 because good projections of wastewater treatment needs are available for that date.)

Because of the small scale of testing to date, reliable estimates of the process's applicability to large plant design flow cannot be made. In general, process simplicity and cost savings appear most advantageous for small, dispersed deployment. On the other hand, effective collection, processing, and use of offgas should favor large plants (above 5 mgd).

Little testing of industrial wastes has been performed, but the resource of degradable organics in industrial wastewaters suggests a potential national energy benefit of the same order of magnitude as that for municipal wastewaters.

III. ANALYSIS OF SPECIFIC TOPICS

A. INTRODUCTION

This section describes the environmental, energy-related, and economic factors essential to an assessment of the ANFLOW process. The assessment begins with consideration of EPA's discharge requirements for POTW's and the ways that those requirements govern performance of systems that might include the ANFLOW process. From this consideration emerges a set of hypothetical plant schematics including ANFLOW, activated sludge, or trickling filter processes. The latter two processes are those most often used to achieve secondary treatment. These plant schematics are intended to produce roughly equivalent (and legal) effluents from typical equivalent influents. The schematics are then compared with each other on the basis of energy and cost. With the resultant facts and figures, assessments are made regarding the future market penetration and national energy implications of the ANFLOW process.

Much of the information on the ANFLOW process was available in a report(1) written for ORNL by Associated Water and Air Resources Engineers, Inc. (AWARE). The AWARE report included:

- A literature review on anaerobic treatment of wastewaters and sludges.
- Descriptions of ANFLOW test sytems and experimental data gathered by ORNL.
- Application of the above to a conceptual design of a treatment system that included the ANFLOW process and that would be expected to provide an acceptable effluent.
- An economic comparison between the system using ANFLOW and another conceptual system based on the activated sludge process.
- Preliminary investigation of market potential.

A summary of the AWARE report's findings regarding advantages and disadvantages is provided in Table 1. Some of the disadvantages listed are conceptual only. For example, susceptibility to, and recovery from, upset may be minimized by the fixed film system. Outer layers of these films may suffer from upsets, leaving lower film layers (and system performance) less affected. Also, odor potential can be lessened by a system design that keeps the anaerobic fluid in closed units until it is aerated.

In relation to the present JBF evaluation of the ANFLOW process, the AWARE report has provided background information that has been used as a starting point for several of the analyses included herein. The AWARE report provided information on ANFLOW methane production, system design, and overall operating characteristics. It also provided some basic information that was useful in the development of our economic and energy analyses. The availability of more recent data on these factors led to updated cost and energy estimates in the later sections of this report. In addition, critical review of the available data by JBF led to estimates of Process performance that we consider more realistic than those previously available.

Table 1. Advantages and Disadvantages of the ANFLOW System Compared to Aerobic Systems, as Delineated in the AWARE Report

ADVANTAGES	DISADVANTAGES
1. Energy-conservative relative to aerated systems.	1. Susceptibility to upset factors; e.g., ammonia, heavy metals, cations, shock loadings, pH, temperature variations, some organics, and cyanide.
2. Offgas recovery and use can provide fuel savings.	2. Is less responsive and requires more time to recover from upset, spills, etc., because of slow anaerobic bacteria growth characteristics.
3. No need for primary clarification.	3. More odor potential.
4. Low sludge production so sludge handling facilities and related energy use are minimized.	4. Inherent solids clogging - fouling potential as a result of upflow filtration.
5. Simplicity relative to aerobic technologies because neither sludge nor effluent must be recycled to the reactor.	5. High effluent ammonia concentrations expected.
6. Requires less land area than most conventional systems.	

Source: Reference 1

B. INFORMATION GAPS

Several unknowns that can only be resolved by further research and development impede confident assessments of ANFLOW's full-scale potential. Some of these unknowns are listed below:

- Energy consumption and cost estimates are based on hypothetical scale-ups of a 5,000 gpd pilot plant. Periodic reassessment will be required as larger ANFLOW units are built and demonstrated.

- There is little information concerning the potential applications of the ANFLOW process in industry. For example, information is needed to determine what industries may use ANFLOW and save energy and money in the process, and to determine what types of design modifications would be necessary to adapt ANFLOW to the treatment of different industrial effluents.

- More information is needed on effluent quality from ANFLOW and the ability of the process to meet effluent standards under various regulatory and environmental circumstances. Such information would be useful for determining more firmly the appropriate upstream and downstream processes in a wastewater treatment plant based on the ANFLOW process.

- ANFLOW operating data under varying climatic conditions are needed to assess the applicability of ANFLOW in different regions of the U.S.

- Sludge production rates, while certainly lower than those of conventional processes, are not well defined.

C. ENVIRONMENTAL FACTORS AND SYSTEM DESIGN

Decisions about wastewater treatment methods are generally made by considering the least costly way to meet effluent requirements. Those requirements usually specify secondary treatment to meet national effluent standards on BOD and suspended solids. Standards for publicly owned treatment works (POTW) are:

- BOD_5 - 30 mg/ℓ (30-day avg.), 45 mg/ℓ (7-day avg.)

- TSS - 30 mg/ℓ (30-day avg.), 45 mg/ℓ (7-day avg.)

- Minimum 85 percent removal for both. Therefore, if influent < 200 mg/ℓ, effluent must be < 30 mg/ℓ (e.g. 100 in, 15 out)

In locations that are "water-quality limited", requirements for specific treatment plants may specify advanced treatment because a secondary effluent would degrade receiving waters. Conversely, effluents that do not meet secondary treatment standards may be permitted in some cases (e.g. small systems and those with marine outfalls).

The issue of relaxed standards for some effluents is particularly germane to the assessment of the ANFLOW process because, as later discussions will show, the effluent often does not meet secondary standards without further treatment. Under Section 301(h) of the Clean Water Act, EPA can modify (relax) secondary treatment standards for dischargers who can demonstrate that receiving waters would not be adversely affected by a discharge not meeting the national standards. The most common type of discharge that has been suggested for 301(h) modification is the marine outfall, and EPA is evaluating many applications for modification from coastal cities.

This assessment of ANFLOW process potential, therefore, must consider the process's likelihood of meeting alternate discharge requirements. The overall question is addressed in several parts, including:

- Removal efficiency of ANFLOW as a unit process;

- Characteristics of ANFLOW effluents that may differ from conventional system effluents;

- Potential process trains that include ANFLOW, with their overall removal efficiencies.

1. ANFLOW Process Performance

The major source of operating data and of evaluations of ANFLOW performance is the AWARE report(1). In addition, ORNL investigators have provided some data on process behavior as affected by abnormal or transient influent characteristics.

a. BOD Removal

Data on BOD removals are available from ORNL in four principal forms:

- Raw data in Appendix A of the AWARE report.
- Averaged summary data in the body of the AWARE report and in papers prepared by ORNL(2).
- ORNL progress reports made available for this study.
- Previously unpublished data made available for this study.

BOD removals in the pilot plant ANFLOW system were between 40 percent and 68 percent during 1977 and 1978. Effluent levels during this period were in the 32 to 97 mg/ BOD range with an average of 62.

One important factor in assessing the BOD removal characteristics of the ANFLOW process is the fraction of effluent BOD that is soluble. The balance in the effluent between soluble and insoluble BOD affects two important judgments:

- Interpreting the removal mechanism (physical or biochemical) and,
- Selecting approaches to upgrade the effluent.

In most cases, upgrading of the effluent will be necessary to bring BOD to within acceptable discharge limits. If the BOD remaining to be removed is chiefly soluble, then physical removal processes such as sedimentation or sand filtration should have little effectiveness. An oxidative or adsorptive process would then be indicated. It may be possible to achieve oxidation by designing a sand filter to support aerobic microbial activity, but such a process remains to be proven at full scale. Some pilot scale information shows promise(3).

Detailed sampling and analyses were performed by ORNL during a three-week period in 1978 to assess the behavior of the soluble and particulate portions of BOD in the ANFLOW pilot plant.

A summary of the resultant data is shown in Table 2.

Based on these data, the AWARE report concluded that no soluble BOD removal was achieved by the ANFLOW pilot plant. The AWARE report acknowledged the possibility that influent soluble BOD was being removed, but coincidentally replaced by BOD caused by microbial degradation products and metabolites. By observing daily patterns of influent and effluent soluble BOD, however, the

Table 2. SUMMARY OF PILOT PLANT DATA FOR JULY 24 - AUGUST 11, 1978

	INFLUENT (mg/ℓ)		EFFLUENT (mg/ℓ)		Percent Removal
	Mean	Std. Dev.	Mean	Std. Dev.	
BOD, Total	142	51	60	11	58
Soluble	22	11	23	11	0
TOC, Total	140	100	49	27	65
Soluble	15	8	13	8	13

AWARE investigators noted that parallel fluctuations occurred. This pattern was cited as evidence that the effluent soluble BOD was unaltered from the influent soluble BOD.

As a further check on the ANFLOW system's ability to remove soluble organics, ORNL spiked the pilot plant influent with soluble organic carbon on a few days in the fall of 1978. The results, together with results from days in the same period when no spiking was done, are shown for TOC in Table 3. (BOD was not measured, but note the close correspondence between BOD and TOC as shown in Table 2.) These data show an average soluble TOC removal of 36 percent with supplemental soluble carbon (range 9 - 67 percent), and 22 percent for unaltered raw sewage (range 0 - 94 percent). The scatter in these data show the obvious need for more definitive testing, but a tentative inference can be made that some removal of soluble BOD occurred.

These data sets on soluble BOD removal have been analyzed for this report. Removal of soluble BOD appears not to be related (based on the data) to hydraulic loading rate or temperature. Some evidence suggests that, when influent soluble BOD is low ($\leq$ 25 mg/ℓ, approximately), removal of soluble BOD is poor. This evidence is not strong, however, and further testing is indicated.

Regardless of influent levels and removal efficiency, effluent soluble BOD appears consistently higher than 15 mg/ℓ. This fact is applied later in this report in the discussion of polishing techniques.

b. Suspended Solids Removal

During 1977 and 1978, while the ANFLOW pilot plant was being operated at design loading rates (less than 5000 gpd), suspended solids removal rates were fairly consistent, ranging from 64 percent to 83 percent. Effluent values of total suspended solids, based on averages derived approximately on a monthly basis, ranged from 16 to 63 mg/ℓ, with a long-term average of 29 mg/ℓ.

Data from pilot plant operation have been interpreted by Genung, *et al.*[2] to indicate the need to flush accumulated solids from the reactor. Otherwise, the ability to remove suspended solids deteriorates over time.

Table 3. Soluble TOC Removal by ANFLOW Pilot Plant

Feed Rate (gpd)	Soluble TOC in Feed (ppm)	Soluble TOC in Effluent (ppm)	Percent Removal
1000	9	13	-
1000	12	10	17
1000	15	20	-
1000	18	16	11
1000	20	20	-
1000	20	9	55
1000	20	25	-
1000	35	2	94
1000[a]	45	22	51
1000[a]	75	25	67
5000[a]	32	25	22
5000[a]	55	24	56
5000[a]	32	22	31
5000[a]	47	34	28
5000	25	25	-
5000	28	26	7
5000	25	20	20
5000	21	15	29
7000	25	13	48
7000[a]	32	25	22
7000[a]	55	50	9

[a]Supplementary soluble carbon added to feed stream.

c. Other Parameters

In addition to the parameters discussed above, detailed data are available for volatile suspended solids, pH, and temperature. No information is available on the fate of metals in ANFLOW reactors. Another important question is the fate of nitrogen forms.

(1) Metals. Heavy metals such as lead, cadmium, and copper usually are removed from municipal wastewaters via the sludge in aerobic biological treatment plants. Because ANFLOW reactors yield so little sludge, the fate of metals in these reactors may be of concern. Metals may become accumulated in the microbial films, or the digestion processes occuring in the column may release metals into the effluent. Similar questions can be raised about toxic organics. Short-term tests with bench-scale reactors at ORNL showed promising results for removal of Pb, Cu, Ni, and Cr, but long-term fate remains uncertain.

(2) Nitrogen Forms. In an aerobic biological system, ammonia-nitrogen is oxidized to nitrate if temperatures and residence times in the reactor are proper. In an anaerobic system such as ANFLOW, this reaction (known as nitrification) will not occur. Unacceptable levels of ammonia/ammonium may therefore appear in ANFLOW effluents. Ammonia-nitrogen is toxic to aquatic organisms and exerts BOD; this BOD is often not detected in a 5-day BOD test because the conversion of ammonia to nitrate usually takes longer than 5 days. More data on nitrogen forms are needed to assess this potential problem, and to provide a design basis for nitrification or other processes to control effluent nitrogen forms.

d. Process Stability

A limited amount of information is available regarding the ANFLOW process's behavior during episodes of shock loading, and this information was furnished to JBF by ORNL.

(1) High Metal Content/pH Fluctuations. Two incidents, probably caused by plating waste discharges to the wastewater collection system, were observed during pilot plant testing. On March 4-5, 1977, influent pH reached 12.7 for a brief period (less than one hour), followed by approximately 12 hours of pH values in the 8.5-9.0 range. Influent pH before and after this aberration was approximately 8.0. No effect on the effluent (pH 7) was observed. Composite samples of the pilot plant feed taken during this period were analyzed at 83 mg/ℓ nickel and 85 mg/ℓ cyanide.

On October 28-29, 1977 a shock load of acidity entered the pilot plant. Feed values between pH 2 and 3 persisted for more than 6 hours. Effluent pH dropped from 6.7 to 5.6 before recovering. Effects on gas production of these events are difficult to interpret from the available data.

These results show promise for process stability but extensive experience is required to confirm that promise.

(2) Organic Shock Loading. Many communities where food processing, organic chemical, or other industries discharge wastewaters high in organic content to municipal sewers face periodic shock loads of oxygen-demanding substances. Because these shock loads often are poorly treated by conventional systems, the response of the ANFLOW process to organic shock loads is of interest. Data are not available to assess this question, however. (During the Fall of 1978, supplementary solids were added to the pilot plant feed, but these were digested solids initially collected from a draining of the ANFLOW unit and probably were mostly nonvolatile, i.e., low in contribution to BOD).

e. Solids Production

In response to a question on this subject, ORNL has provided in a letter to JBF (November 14, 1979) a concise discussion, which is repeated in part here:

> "A comprehensive answer to this question will not be available until the 50,000 gpd pilot plant is operated with the on-line pretreatment and polishing steps which will be associated with the ANFLOW column. Sludge

production rates for the different unit operations will then be evaluated, and the rate determined for the ANFLOW column will depend on the operation of the pretreatment and polishing steps under conditions found optimal for the total treatment system.

"During the 5000 gpd pilot plant project, approximately 2.1 million gallons of wastewater passed through the ANFLOW column for treatment. After 22 months of operation, approximately 800 pounds of "sludge" were removed. It could be stated, then, that the sludge production rate was approximately 380 pounds of sludge for each million gallons of wastewater treated. This would, however, include some materials which would ordinarily be removed by pretreatment operations. It would also not include some materials which would ordinarily be removed (and therefore contribute to overall sludge production rates) by downstream polishing steps. The sludge production rate would also depend on the frequency of backwashing the ANFLOW column (since the efficiency of long-term digestion processes would be altered) and the extent to which fixed-films were reduced in volume by the backwashing processes."

Sludge production rates from conventional systems that include primary settling and activated sludge or trickling filter processes are usually about 2000 pounds of sludge solids per million gallons of domestic wastewater treated.

f. Summary: Process Performance

As a basis for conceptual design of systems to meet effluent standards, Table 4 has been prepared.

2. Conceptual Designs

To provide a basis for cost and energy estimates and comparisons, flow sheets for treatment systems based on ANFLOW and on aerobic processes have been developed.

In general, these flow sheets are similar to those for ANFLOW and activated sludge in the AWARE report. Some important differences/additions used here are:

- A flow sheet based on the trickling filter process is provided here.
- A system based on ANFLOW with no effluent polishing is considered with a view toward section 301(h) standards relaxation.

The principal assumptions behind the flow sheets are listed in Table 5, and the flow sheets themselves are shown in Figures 2 and 3. The assumption that ANFLOW with effluent filtration can meet an effluent BOD standard of 15 mg/ℓ seems optimistic because of the soluble BOD in ANFLOW effluents. Some biooxidation in the filtration system is necessary. If activated carbon were required, ANFLOW's cost and energy position at sites with stringent effluent requirements would be severely downgraded.

This discussion of environmental factors and system designs provides the basis for addressing the energy and cost issues in this study.

Table 4. Summary of ANFLOW Performance, Based on Pilot Plant in Oak Ridge, TN.

	BOD5		Suspended Solids			
	ANFLOW	Secondary Treatment Standards	ANFLOW	Secondary Treatment Standards	Metals and Other Toxics	Ammonia
Percent Removal	40-68	$\geq$85	64-83	$\geq$85	Removals unknown; Standards lacking due to emphasis on industrial pretreatment.	Removals unknown but ANFLOW probably increases wastewater NH_3/NH_4^+. No national standards but some water-quality limited sites have local restrictions.
Average Effluent Levels (mg/ℓ)	62	$\leq$30	29	$\leq$30		

Table 5. Treatment Systems Assumed to Meet Various Performance Requirements

Influent Quality* BOD / SS	Effluent Quality* BOD / SS	Effluent Upgrading Step Needed for System: Activated Sludge	Trickling Filter	ANFLOW
300/300	30/30	-	-	Filter
100/100	15/15	Filter	Filter	Filter
300/300	60/40	-	-	-

* All values in mg/ℓ

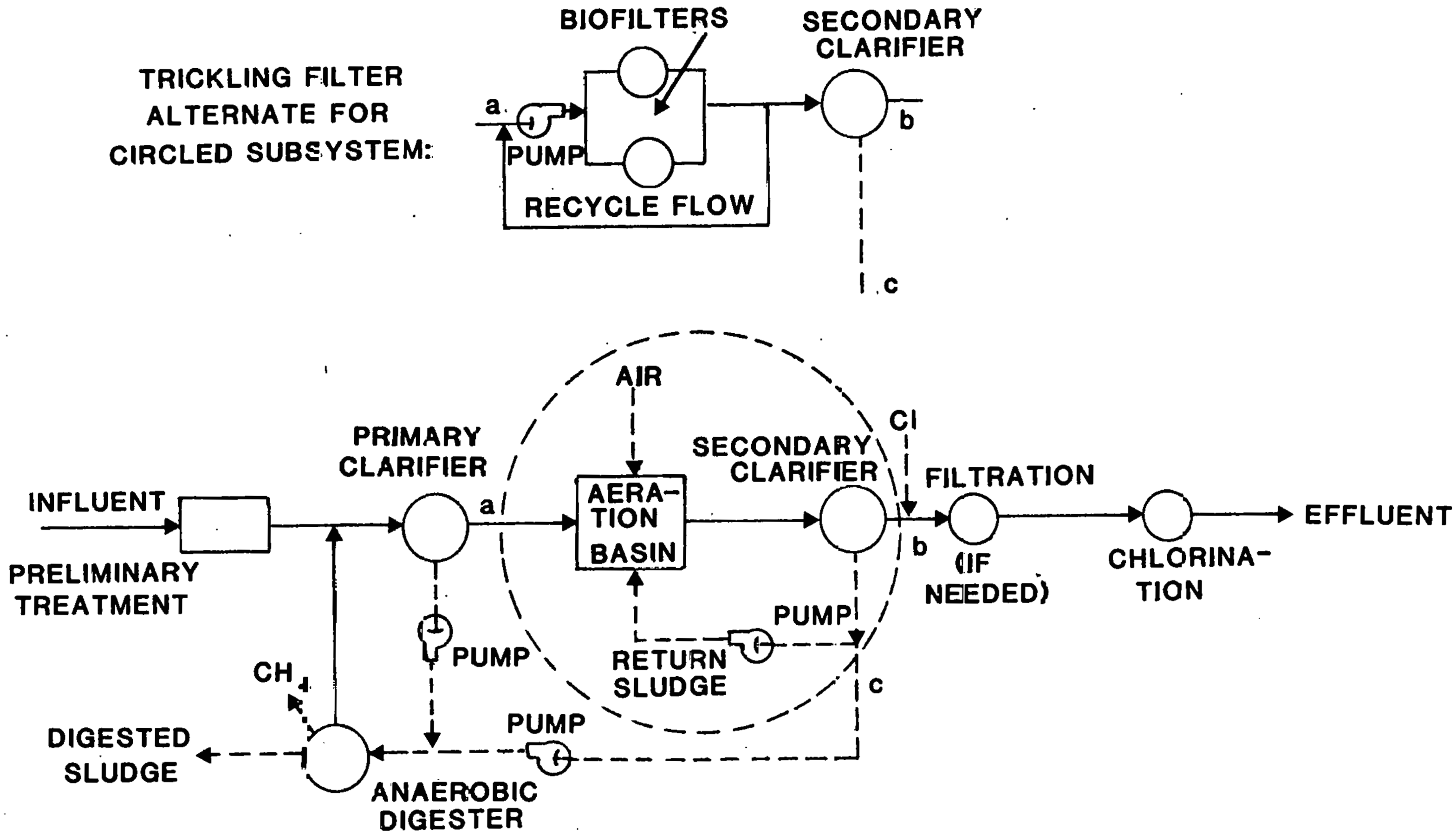

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Figure 2. Flowsheet for Aerobic Systems

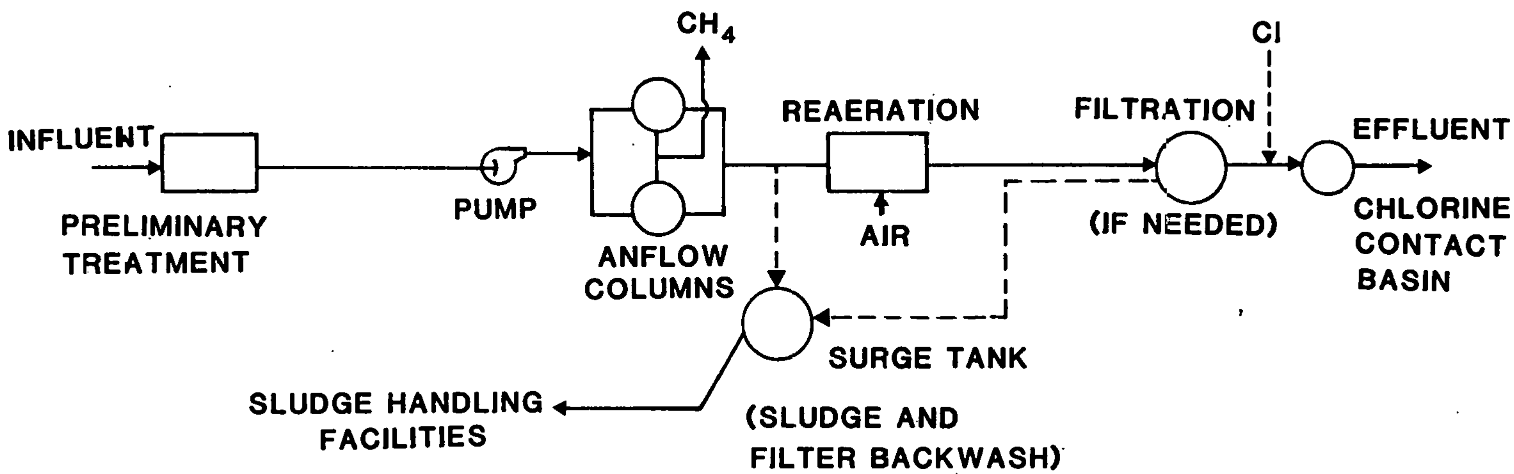

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Figure 3. Flowsheet for ANFLOW System

D. ENERGY FACTORS

In this section, the consumption of energy by ANFLOW systems is compared with that of conventional wastewater treatment systems. The energy yield from methane that may be recovered in ANFLOW systems is also considered.

1. Municipal Wastewaters

a. Energy Consumption

This discussion of energy consumption ignores for the present the generation and use of methane within the treatment plant. Methane generation by ANFLOW and other systems is considered later in this secion on energy, followed by summary comparisons among the various options for wastewater treatment.

Energy requirements for operation of the ANFLOW process are compared to those of other types of municipal wastewater treatment systems. The treatment systems to be considered in the analysis include conventional activated sludge and high rate trickling filter.

The energy requirements were developed from information on each unit process of each treatment system based on various literature sources. The systems, as considered, have been assembled to meet roughly equivalent effluent characteristics.

The following unit processes have been considered in the analysis:

- Preliminary treatment, including screening, comminution and grit removal, required to some degree for all treatment systems.
- Primary sedimentation, required for all systems except ANFLOW.
- Biological process - most require considerable energy, mainly for pumping and aeration. However, the energy requirements for ANFLOW and trickling filters are low in that aeration is unnecessary.
- Secondary sedimentation, required in the activated sludge and trickling filter systems to settle sludge.
- Disinfection (chlorination), required for all systems.
- Sludge handling, including pumping, digestion, dewatering, and disposal in a sanitary landfill, required for all sludge producing processes (activated sludge, trickling filter). As stated above, methane generation and use are not considered until later.
- Effluent polishing techniques, including granular media filtration and granular activated carbon adsorption, one or more of which may be necessary as an addition to the candidate processes in order to meet secondary effluent standards.

A detailed review of available information on energy consumption revealed considerable variation among the sources. Differences in assumptions can sometimes explain this variation. For example, pumping energy estimates depend on the assumed head. Other sources of variation include varying assumptions on BOD removal, and apparent errors. Energy consumption data as given by various sources were reviewed and values were selected by JBF as appropriate to the needs of this study. One element of the energy accounting - ANFLOW sludge handling - was not available from any source. Values were assumed based on the approximate proportion of sludge generation by ANFLOW relative to aerobic processes.

Plant sizes of 0.1 and 1.0 mgd are assessed here. Larger plant sizes have not been compared because the emphasis at ORNL has been on flows up to 1 mgd, and therefore most of the available information on ANFLOW is at that flow or less. Two factors have led to this emphasis on small plants:

- Scale-up of pilot plant experience is valid only up to a limited plant size. Hydraulic investigations on larger demonstration plants are needed to provide a basis for design of the large reactors needed above 1 mgd.

- Preliminary economic studies by AWARE show that the costs of packing media (with little or no economy of scale) make ANFLOW relatively costly at higher flows, where conventional systems exhibit significant economies of scale.

Moreover, present trends suggest more small, decentralized wastewater treatment facilities in the future.

Energy requirements (in MWhr/yr) for the municipal wastewater treatment alternatives at plant capacities of 0.1 and 1.0 million gallons per day (MGD) are presented for comparison in Tables 6 and 7 respectively. As shown in these tables, at both plant design flow rates considered, the ANFLOW process requires much less energy than treatment systems based on the activated sludge or high rate trickling filter processes. This is a consequence of ANFLOW's minimal biological process energy consumption and its low sludge production, thus eliminating the need for significant energy use in sludge processing and handling.

The energy conservation value of ANFLOW-based systems is not sensitive to the need for filtration of the effluent. Gravity filtration through sand or multiple granular media is not an energy-intensive process, as the totals with and without filtration in Tables 6 and 7 show. Therefore, ANFLOW's competitiveness according to energy conservation criteria is insensitive to the performance requirements shown in Table 5.

b. Methane Production

(1) Basic Information. Organic waste material retained in the ANFLOW column is biologically degraded to form various end products; and, under the proper conditions, the ultimate end products would consist of a mixture of methane and carbon dioxide, plus smaller amounts of nitrogen, hydrogen sulfide, and mercaptans. Assuming an average volumetric gas compositon of 70 percent methane and 30 percent carbon dioxide, and the fact that a portion of the TOC (total organic carbon) in the wastewater is utilized

Table 6. Comparative Energy Requirements for a 0.1-mgd Treatment System (MWhr/yr)

Unit Process	Activated Sludge	Trickling Filter	ANFLOW
Preliminary Treatment	13	13	13
Pumping	8	8	8
Primary Sedimentation	3	3	–
Biological Process	25	2	8
Secondary Sedimentation	4	4	–
Chlorination	3	3	3
Sludge Handling*	21	19	3
TOTAL w/o Filtration	77	52	35
TOTAL with Effluent Filtration	80	55	38

Source: JBF estimates based on data in Refs. 1, 2, 4, 5, 6, 7.

* Pumping, aerobic digestion, drying beds, haul to landfill (5 mi. one way)

Table 7. Comparative Energy Requirements for a 1-mgd Treatment System (MWhr/yr)

Unit Process	Activated Sludge	Trickling Filter	ANFLOW
Preliminary Treatment	20	20	20
Pumping	100	100	167
Primary Sedimentation	7	7	-
Biological Process	250	50	-
Secondary Sedimentation	10	10	-
Chlorination	10	10	10
Sludge Handling*	120	110	18
TOTAL w/o Filtration	517	307	215
TOTAL with Effluent Filtration	540	330	238

Source: JBF estimates based on data in Refs. 1, 2, 4, 5, 6, 7.

* Pumping, aerobic digestion, drying beds, haul to landfill (5 mi. one way)

for cellular synthesis, the theoretical methane yield for the ANFLOW process should be approximately 18.5 cu. ft/lb TOC removed. For domestic wastewater, the same value applies for gas production on a BOD removal basis, because BOD_5 and TOC are usually similar in concentration for a given sample.

AWARE Inc.(1) has reported on experimental studies of methane gas production rates from the ANFLOW pilot plant. The findings of these investigations include:

- An increase in gas production with increasing temperature was demonstrated. During the coldest weather of the study period when temperature dropped to 11-13°C, there was a decrease in gas production. It was also noted that the methane yield (at 25°C) was higher when ANFLOW columns were held at constant temperature than when the temperature was varied.

- Increase in gas production was shown to parallel an increased loading rate to some degree. These results were not as clear as those for the temperature dependence. Available data do not allow unambiguous separation of the effects of temperature and loading.

- Gas production and organic removal rates do not necessarily correlate on an instantaneous or even monthly basis, because organic matter will tend to accumulate in the ANFLOW column during periods of slow decomposition (e.g., during cold weather) and decompose at a later time when favorable conditions exist. Thus, gas production will be proportional to organic removal only under steady-state conditions.

- The actual amount of methane produced in the ANFLOW pilot plant column amounted to 33 percent of the theoretical value under conditions of temperature variations. A bench-scale column at constant temperature yielded approximately 50 percent of the theoretical methane volume.

The partitioning of methane between the liquid and gaseous phases has important implications relating to its recovery and use. The methane production values cited above represent the summation of gaseous methane recovered in the reactor headspace and the dissolved methane in the reactor's liquid effluent.

(2) Projections of Actual Yield. The AWARE report presented expected computed yields of methane in ANFLOW systems treating domestic wastewater. Those values are shown in Table 8. The assumptions behind this table were not completely stated, but have been inferred for this study.

Table 8. Offgas and Power Projections from the AWARE Report

Influent Strength	Offgas (c.f./day) for Two Plant Sizes		Available Power (hp) for Two Plant Sizes	
	.05 mgd	1 mgd	.05 mgd	1 mgd
100 mg/ℓ BOD	469	9,580	3	60
300 mg/ℓ BOD	1,780	35,820	11	225

To explain the inferences made here, and to put them into perspective, Table 9 has been prepared.

Table 9. Basis of Inferred Assumptions Behind AWARE Offgas Projections

Offgas (c.f./day) (See Table 8)	Implied Rate of Offgas Production (c.f./10^6 gal)	Maximum Actual Rate of Offgas Production* (c.f./10^6 gal)	
		Pilot Plant	Bench Scale
469 (Weak Influent)	9,380	825	8,198
1,780 (Strong Influent)	35,600	1,623	8,182
9,580 (Weak Influent)	9,580	861	8,622
35,820 (Strong Influent)	35,820	1,671	9,531

*Values shown are the highest monthly averages computed from data in the AWARE report from strong and weak wastewaters in test columns.

A review of Table 9 suggests that the offgas data from the bench scale column were directly applied to the estimation of offgas production from weak wastewaters. This column was operated at relatively constant room temperatures, received none of the variable feed qualities that the pilot plant experienced, and treated stronger wastewaters than did the pilot plant. Relatively low pilot plant gas production rates were ascribed to gas leaks in the column. The gas yields projected by AWARE for stronger influent (300 mg/ℓ) are 3.7 to 3.8 times the yields for 100 mg/ℓ influent. A better removal rate for organic carbon is therefore implied for stronger wastewater. To infer the removals used by AWARE, computations have been performed using other information in the AWARE report.

The data shown in our Table 8 are from AWARE's Table 6-6. That table cited an equation used to compute power recovery:

$$P = 0.98\ Q\ \Delta\ TOC$$

Where:

P = power generated, hp
Q = liquid flowrate, mgd
Δ TOC = TOC removed, mg/ℓ

This equation and the power values in Table 8 have been used to infer TOC removals. Results indicate that 75 percent removal was assumed by AWARE for 300 mg/ℓ influent, and 61 percent removal for 100 mg/ℓ influent. These removal rates appear quite optimistic in view of the pilot plant's performance (34 percent to 68 percent removal, average 52 percent) and the bench scale column's performance (30 to 82 percent removal, average 59 percent). However, average performance may be pessimistic because the ORNL investigation was intended as a feasibility study rather than as an optimized commercial demonstration.

Operating data from the ANFLOW Pilot Plant at the Oak Ridge Treatment Plant are not applicable to gas production estimates for two reasons:

- ORNL suspects that the column was not gas-tight. Therefore, direct gas production measurements are considered inaccurate. Moreover, a reliable value for $\frac{\text{lb TOC destroyed}}{\text{lb TOC removed}}$ is not available because AWARE estimated this value based on gas production data, assuming no gas leaks.

A comparison can be made between the AWARE projections and the methane production found during anaerobic upflow experiments at Cornell University. Using an expanded bed fixed film reactor to treat a glucose/nutrient mixture, Switzenbaum and Jewell[8] produced 5.5 to 7.5 scf methane per pound of COD removed. The processes in the Cornell reactors should be similar to those in the ANFLOW reactors because loading rates were similar and the inoculum was bovine ruminant fluid. For glucose, the COD/TOC ratio should be 2.66.

Therefore, a completely independent data set from another laboratory allows the following assumptions and computation for methane yield from a 1-mgd plant:

Assumptions (Based on data in reference 8):

- Percent removal of TOC: 62 percent
- Percent of removed TOC that is biochemically converted in the column: 82 percent
- Methane production per TOC destroyed:

$$\frac{6.5 \text{ scf } CH_4}{\text{lb COD}} \cdot \frac{2.66 \text{ lb COD}}{\text{lb TOC}} = 17.3 \frac{\text{scf } CH_4}{\text{lb TOC}}$$

- Wastewater influent TOC:

$$200 \frac{\text{mg}}{\ell} \text{ COD} \times \frac{\text{mg TOC}}{2.66 \text{ mg COD}} = 75.2 \text{ mg}/\ell$$

Computation:

$$\frac{\text{mg TOC entering}}{\ell} \left| \frac{\text{gm}}{\text{mg}} \right| \frac{\text{lb}}{\text{gm}} \left| \frac{\text{S.C.F. } CH_4}{\text{lb TOC}} \right| \frac{\text{lb TOC removed}}{\text{lb TOC entering}} \left| \frac{\text{lb TOC destroyed}}{\text{lb TOC removed}} \right| \frac{\text{gal}}{\text{day}} \left| \frac{\ell}{\text{gal}} \right.$$

$$\frac{75.2}{} \left| \frac{}{1000} \right| \frac{}{454} \left| \frac{17.3}{} \right| \frac{.62}{} \left| \frac{.82}{} \right| \frac{10^6}{} \left| \frac{3.785}{} \right. = 5{,}512 \text{ scf per day}$$

This value should be somewhat optimistic because it is based on treatment of glucose. In addition, the Cornell data represent steady state, constant-temperature, controlled conditions.

Tabular comparison of the AWARE projections and the two computed by JBF based on independent data are provided in Table 10.

Table 10. Comparison of Methane Yield Projections

Source	Basis	Methane Yield (s.c.f. per day for 1 mgd plant with dilute influent of 75-100 mg/ℓ TOC)
AWARE Report(1)	Offgas from Bench Scale ANFLOW Reactor (25°C) at 70 percent CH_4. Based on the average of three data points.	6,566
This study	Operating data from Switzenbaum and Jewell(8) treating glucose at bench scale.	5,512

It is likely that any system operating under realistic feed conditions would yield less methane than these controlled laboratory reactors. For the purpose of developing approximate estimates, however, the value of 5,500 cu ft methane per day will be used for a 1-mgd plant treating dilute (100 mg/ℓ TOC) wastewater.

Other plant sizes at the same influent strength will be scaled linearly according to flow rate. For more concentrated influent (300 mg/ℓ TOC), the methane production will be scaled up by the factor 3.7 as in the AWARE report. Evidence in the AWARE report and in Switzenbaum and Jewell(8) indicates better TOC removal and better methane production at higher feed TOC concentrations.

(3) Practical Considerations. Earlier in this section, reference was made to the partitioning of methane between the offgas and dissolved methane in the liquid effluent. Data contained in the AWARE report have been used here for computations leading to the values shown in Table 11. This table ignores the pilot plant because of its reported gas leaks. (Computations show that only 2 percent to 29 percent of the methane found in the pilot plant was in the offgas, the balance presumed lost through gas leaks or contained in the effluent.)

Much of the produced methane is contained in the effluent, in dissolved form. This condition is not encountered in anaerobic digesters, primarily because their much longer hydraulic residence time produces a liquid effluent flow that is small relative to the volume of the reactor. Equipment designed to

Table 11. Partitioning of Methane Between Offgas and Liquid Effluent

Gaseous CH_4 (ℓ/day)*	Total CH_4 (ℓ/day)**	Percent of Total CH_4 That is Gaseous
2.3	4.9	47
3.6	6.2	58
1.4	4.0	35
2.8	5.5	51
3.5	6.6	53
3.9	7.2	54
4.1	7.3	56
4.1	7.0	59
3.1	5.1	61
4.7	8.0	59
		Average: 53.3 percent

* AWARE, Table 5-2. All data weekly averages.

** AWARE, Table 5-6. All data weekly averages.

recover dissolved methane is not available and it is beyond the scope of this investigation to hypothesize how it might be designed and operated, and at what cost. Widespread use of ANFLOW would probably stimulate the development of this equipment, however.

The most likely approach to recovering dissolved methane would be a vacuum degasifier. Such a system would also capture dissolved CO_2 if the pH were low enough (below pH 6.3, dissolved CO_2 exceeds HCO_3). At higher pH, however, dissolved inorganic carbon would be in the bicarbonate form and, therefore, would not behave as a dissolved gas.

Of course, equipment designed to capture, clean, store, and use offgas is available. A survey of this technology is provided in a recent EPA report(5). Although the applications seen in that report were for sludge digesters, the application to ANFLOW columns is straightforward.

To avoid corrosion in equipment that would handle and burn the gas, impurities such as hydrogen sulfide and water should be removed. Wesner, et al.(5) consider a chemical scrubbing system to be the most suitable means to clean the offgas. Compression and storage at 45 psi normally completes the digester gas preparation. If gas from ANFLOW plants or from digesters at conventional plants were to be used off-site in a pipeline system, removal of carbon dioxide and nitrogen would also be necessary to upgrade the heating value.

Offsite use of fuel gas from treatment plants has not been investigated comprehensively in the literature because aerobic treatment plants do not produce surplus energy; gas use has always been on-site. (Plants may exist whose high sludge yield allows anaerobic digester gas to produce surplus methane for off-site use, but we are aware of no such plants.) A comprehensive review of landfill gas use has, however, been completed by Ham, et al.[9] This gas is normally about 47 percent methane and 47 percent carbon dioxide. The methane content is lower than ANFLOW gas, but the nitrogen content is also lower. Nitrogen content of ANFLOW offgas appears to be in the 20 percent range (by difference, based on discussion with ORNL investigators). Removal would probably be by liquifaction, an expensive and energy-intensive process. Ham, et al. listed several options for gas use, shown in Table 12. For specific applications, technology and markets are available for a range of off-site gas users.

Table 12. Alternative Gas Fuel Applications

Application	Processing Required	Higher Heating Value (HHV) (BTU/scf)	Limitations
Direct Fuel	Condensate removal	460 to 490	Must be consumed at the source
Direct Fuel	Dehydration	460 to 490	Can be transported via pipeline moderate distances
Direct Fuel	Dehydration and partial carbon dioxide removal	650 to 750	Can be transported moderate distances and mixed with natural gas at low ratios.
Direct Fuel	Dehydration, carbon dioxide and nitrogen removal	960 to 990	Can be mixed with natural gas at intermediate to high ratios

Adapted from Ham, et al.[9]; ANFLOW offgas should have 20 percent to 30 percent higher heating value than values shown here for landfill gas.

Another practical consideration is the plant size required to justify use of offgas. Anaerobic digester gas is normally used only in treatment plants with

24-hour attendance for reasons of safety and protection of equipment. Operator duty for 24 hours is limited to plant flows well above 1 mgd. Moreover, some equipment for the use of offgas is not available. Wesner, et al.[4] stated that engine-generator sets are not commonly available for gas production less than 54,000 scf/day. For an ANFLOW plant, the flow required to generate this volume would be approximately 5 to 15 mgd, depending on feed strength. Smaller units are beginning to appear on the market. One can assume that the equipment will become more available as the value of recovering methane increases, but the present situation provides little information on costs and efficiencies of small equipment.

(4) Comparison with Conventional Systems. A good amount of operating data on aerobic biological treatment plants is available. Wesner, et al.[4] state that a 1-mgd activated sludge plant treating domestic wastes will typically yield 10,845 scf/day of offgas from its anaerobic sludge digestion system. At 70 percent methane, the methane volume is 7,592 scf/day. Trickling filter plants normally produce about 90 percent of the values for activated sludge. Other plant sizes can be scaled linearly. Conventional plants of 1 mgd or less normally do not practice anaerobic digestion. It should also be noted that such digestors are generally sized for solids residence times of approximately 10 to 30 days. In order to achieve waste stabilization in that period, the digestors must operate at elevated temperatures (e.g., 95°F); the methane produced by digestion is usually burned to provide the necessary heat.

c. Overall Energy Comparisons Among Treatment Systems

Based on the foregoing discussions, energy consumption and methane production by ANFLOW and conventional systems will be compared. For the reasons described above, these comparisons are for small treatment plant flows: 0.1 and 1.0 mgd.

Whether methane generated in ANFLOW plants of these flow capacities would actually be used is subject to question. The following factors will guide these decisions:

- Complexity of system and required amounts and skill levels of operator attention.
- Capital Cost
- Operating and maintenance (O & M) cost

It appears likely that inexpensive systems could be designed to collect and store ANFLOW offgas from small units. Perhaps the simplest design would be a floating, gas-tight cover built into the top of the column. The weight of the cover could be coordinated with the pressure requirements of the equipment in which the gas was to be burned. It does not appear likely, however, that small plants could justify the equipment needed to recover dissolved methane from the effluent.

These practical considerations are used for developing assumptions for comparisons of systems. Those assumptions are shown in Table 13. Table 14

Table 13. Assumptions Regarding Methane Generation and Use

Size Range (mgd)	Type Treatment	Type Digestion (Conventional Plants)	Offgas Use	Dissolved Methane Recovery
≤1	ANFLOW	–	Yes	No
	Conventional	Aerobic (no methane)	–	–
1-5	ANFLOW	–	Yes	No
	Conventional	Anaerobic	Yes	–
>5	ANFLOW	–	Yes	Yes
	Conventional	Anaerobic	Yes	–

Table 14. Overall Energy Balance Comparisons for Strong Influent

Plant Type	0.1 mgd: Energy[a] Requirements (MWh/yr)	1.0 mgd: Energy[a] Requirements (MWh/yr)	Methane Generated (s.c.f./yr)	Energy Content of Methane (MWh/yr): Total	Energy Content of Methane (MWh/yr): Value as[c] Electricity
ANFLOW	38	238	3,700,000[b]	1110	370
Activated Sludge	77	517			
Trickling Filter	52	307			

[a] Basis: 300 mg/ℓ BOD influent, 30 mg/ℓ effluent. See Tables 5, 6 and 7.

[b] Generation at 1 mgd on weak influent x 3.7 to account for waste strength. Dissolved methane in effluent not included.

[c] Efficiency of engine - generator set = 35 percent.

shows the energy requirements and methane production potential for ANFLOW and aerobic systems treating strong influent. Table 15 is a similar presentation for weak influent. All of the processes are net consumers of energy with weak influent. For strong influent, ANFLOW is a net producer of energy, if the plant is large enough to collect and use the methane.

Table 15. Overall Energy Balance Comparisons for Weak Influent

Plant Type	0.1 mgd	1.0 mgd			
				Energy Content of Methane (MWh/yr)	
	Energy[a] Requirements (MWh/yr)	Energy[a] Requirements (MWh/yr)	Methane Generated (s.c.f./yr)	Total	Value as[c] Electricity
ANFLOW	38	238	1,000,000[b]	300	100
Activated Sludge	80	540			
Trickling Filter	55	330			

[a] Basis: 100 mg/ℓ BOD influent, 15 mg/ℓ effluent. See Tables 5, 6 and 7.

[b] Does not include dissolved methane in effluent.

[c] Efficiency of engine - generator set = 35 percent.

2. Industrial Wastewaters

The ANFLOW process has not been tested with industrial wastewaters. For some industries with degradable organic wastewaters and without inhibitory components, ANFLOW should be an effective process because many studies on other types of similar anaerobic filters have shown promise. In the national synthesis that concludes this section, certain industrial sectors are considered with regard to ANFLOW's potential. In the absence of any data on industrial wastes, somewhat speculative assumptions will be required about process performance. Specifically, it will be assumed that the methane generation potential for industrial wastes is similar to that for domestic wastewaters on an organic removal basis. The following assumptions are made:

- 60 percent removal of TOC
- Wastewater influent TOC = 300 mg/ℓ

- Percent of removed TOC that is biochemically converted in the column: 70 percent

- Methane production per TOC destroyed: $\frac{17.3 \text{ scf } CH_4}{\text{lb TOC}}$

These assumptions lead to a computed value of 18,000 scf. CH_4/day for a 1-mgd plant. Another useful expression, computed similarly, is 7.2 scf CH_4/lb TOC entering industrial waste treatment facilities. These values are used in the industrial part of the concluding discussion of this Section (III.F).

E. ECONOMIC FACTORS

1. Development of Cost Data

The purpose of this section is to evaluate the economic competitiveness of the ANFLOW process versus conventional activated sludge and trickling filter installations. Baseline cost estimates for the conventional technologies were generated by means of the U.S. EPA's CAPDET (Computer Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems) model. The program provided March, 1979 dollar figures for two design flow cases (0.05 and 1.0 mgd), and two influent quality criteria (strong and weak). Input assumptions for the CAPDET cost data are presented in Table 16.

Preliminary ANFLOW cost data were available from the AWARE and Oak Ridge reports. They were however, presented without description of several key input assumptions. As a result, their usefulness was greatly diminished. Since the levels of confidence and detail were insufficient to justify a direct comparison with the CAPDET data, several working assumptions and compromises had to be made in the theoretical approach to this evaluation:

- the cost data reported herein are significant indicators of the range of cost relationships in and among the three technologies, not as actual dollar figures to be expected in practice;
- in the absence of data to the contrary, material costs and other site specific factors were assumed to be equal in all cases;
- analogous cost experience with conventional technologies served as the basis for the expansion of ANFLOW cost data; and,
- cost data adjustments were based on the assumption that total capital costs equalled the sum of unit process costs plus land, indirect, and profit and overhead charges.

2. Cost Comparisons

Cost summaries for trickling filter and activated sludge plants for all four combinations of influent quality and design flow are presented in Tables 17 to 20. Similar ANFLOW cost estimates are presented for two design flow cases in Table 21. Estimates for ANFLOW's strong and weak influent cases were not made due to the uncertainty associated with published baseline data. However, ANFLOW should be similar to trickling filters in the insensitivity of cost to feed strength.

ANFLOW construction cost estimates were observed to be lower than those generated for the conventional technologies in several cases. At the 0.05 mgd design flow, ANFLOW costs ranged from a minimum of 26% to a maximum of 30% less than conventional activated sludge or trickling filter installations. At the 1.0 mgd design flow, ANFLOW construction costs were only less than those reported for the activated sludge, low quality ("strong") influent case. The conventional technologies were from 18.5% to 13.0% less expensive to construct than ANFLOW in the following cases:

TABLE 16

Influent Quality, Construction, and O&M

Assumptions Used in CAPDET Data Generation

o Influent Quality

	Strong (mg/l)	Weak (mg/l)
BOD_5	300	100
Total Suspended Solids	250	120
COD	500	200
PO_4	18	18
Total Kjeldahl Nitrogen	45	45
NH_3	25	25
Oil and Grease	80	80
Cations	160	160
Anions	160	160
Temperature	18°C	18°C
pH	7.60	7.60

o Construction

Planning Period = 20 years
Interest Rate = 6 5/8%
Engineering News Record Cost Index = 2910
Pipe Cost Index = 282.8
Large City EPA Index = 163
Land Cost = $2000.00/acre
Pipe Installation Labor Rate = $14.70/hr
Concrete Costs
  wall = $207.00/cu. yd.
  slab = $ 91.00/cu. yd.
Building = $ 48.00/sq.ft.
Excavation = $1.20/cu.yd.
Canopy Roof = $15.75/sq.ft.
8" pipe = $8.70/ft.
8" pipe bend = $83.17/unit
8" pipe tee = $123.09/unit
8" pipe valve = $1289.61/unit

o Operation and Maintenance

Operator's Labor Rate = $7.50/hr.
Electricity = $0.04/kWhr.
Chemical Costs
  lime = $0.02/lb
  alum = $0.04/lb
  iron salts = $0.06/lb
  polymer = $1.62/lb

Table 17

Cost Summary of 0.05 mgd Trickling Filter Plant
Under Two Influent Assumptions

	Low Quality Influent(1)		Cleaner Quality Influent(2)	
I. Investment Cost				
Capital Cost	$507,919		$499,664	
Direct Cost	111,742		109,926	
Total Construction Costs		$619,661		$609,590
Indirect Costs	189,205		186,240	
Land Costs	16,257		16,257	
		205,462		202,497
Total Capital Costs		825,123		812,087
II. O&M Cost				
Operating Labor	17,299		16,915	
Maintenance Labor	7,727		7,566	
Power	6,006		5,948	
Materials	20,656		21,213	
Chemicals	89		89	
Administrative	1,699		1,699	
Laboratory	12,838		12,838	
Total O&M Costs		$ 66,317		$ 66,271

Source: CAPDET

(1) Low Quality Influent Characteristics: TSS 250 mg/l; BOD_5 300 mg/l; COD 500 mg/l; pH 7.60.
(2) Cleaner Quality Influent Characteristics: TSS 120 mg/l; BOD_5 100 mg/l; COD 200 mg/l; pH 7.60.

Table 18

Cost Summary of 0.05 mgd Activated Sludge Plant
Under Two Influent Assumptions

	Low Quality Influent[1]		Cleaner Quality Influent[2]	
I. Investment Costs				
Capital Cost	$547,549		$528,507	
Direct Cost	120,460		116,271	
Total Construction Costs		$668,009		$644,778
Indirect Costs	203,414		196,589	
Land Costs	16,257		16,257	
		219,671		212,846
Total Capital Costs		887,680		857,624
II. O&M Cost				
Operating Labor	20,815		18,762	
Maintenance Labor	8,839		8,005	
Power	6,559		5,433	
Materials	26,832		24,728	
Chemicals	89		89	
Administrative	1,699		1,699	
Laboratory	12,838		12,838	
Total O&M Costs		$ 77,673		$ 72,556

Source: CAPDET

(1) Low Quality Influent Characteristics: TSS 250 mg/l; BOD_5 300 mg/l; COD 500 mg/l; pH 7.60.

(2) Cleaner Quality Influent Characteristics: TSS 120 mg/l; BOD_5 100 mg/l; COD 200 mg/l; pH 7.60.

TABLE 19

Cost Summary of 1.0 mgd Trickling Filter Plant
Under Two Influent Assumptions

	Low Quality Influent[1]		Cleaner Quality Influent[2]	
I. Investment Costs				
Capital Cost	$1,174,322		$1,098,727	
Direct Cost	258,350		241,719	
Total Construction Costs		$1,432,672		$1,340,446
Indirect Costs	452,342		398,773	
Land Costs	20,158		20,158	
Total Capital Costs		1,878,172		1,759,377
II. O&M Costs				
Operating Labor	34,621		32,101	
Maintenance Labor	15,215		14,153	
Power	15,133		14,128	
Materials	32,828		32,483	
Chemicals	1,793		1,793	
Admininistrative	8,355		8,355	
Laboratory	20,212		20,212	
Total O&M Costs		$ 128,159		$ 123,228

Source: CAPDET

(1) Low Quality Influent Characteristics: TSS 250 mg/l; BOD_5 300 mg/l; COD 500 mg/l; pH 7.60.
(2) Cleaner Quality Influent Characteristics: TSS 120 mg/l; BOD_5 100 mg/l; COD 200 mg/l; pH 7.60.

TABLE 20

Cost Summary of 1.0 mgd Activated Sludge Plant
Under Two Influent Assumptions

	Low Quality Influent (1)		Cleaner Quality Influent (2)	
I. Investment Costs				
Capital Cost	$1,358,121		$1,160,486	
Direct Cost	298,786		255,306	
Total Construction Costs		$1,656,907		$1,415,792
Indirect Costs	489,782		420,481	
Land Costs	20,158		20,158	
Total Capital Costs		2,166,847		1,856,431
II. O&M Costs				
Operating Labor	48,522		39,152	
Maintenance Labor	20,985		16,729	
Power	25,559		23,347	
Materials	38,961		35,444	
Chemicals	1,793		1,793	
Administrative	8,355		8,355	
Laboratory	20,212		20,212	
Total O&M Costs		$ 164,389		$ 145,034

Source: CAPDET

(1) Low Quality Influent Characteristics: TSS 250 mg/l; BOD_5 300 mg/l; COD 500 mg/l; pH 7.60.
(2) Cleaner Quality Influent Characteristics: TSS 120 mg/l; BOD_5 100 mg/l; COD 200 mg/l; pH 7.60.

TABLE 21

Cost Summary of 0.05 and 1.0 mgd
ANFLOW Installations

	0.05 mgd		1.0 mgd	
I. Investment Cost				
Captial Cost	281,500		1,348,703	
Direct Costs	114,000		297,000	
Total Construction Costs		395,500		1,645,703
Indirect Costs	189,205		490,437	
Land Costs	16,257		20,158	
Total Capital Costs		$600,962		$2,156,298
II. O&M Costs				
Operating Labor	4,090		11,200	
Maintenance Labor	2,140		4,700	
Power	5,000		7,900	
Materials	6,800		16,100	
Chemicals	90		1,790	
Administrative	1,700		8,355	
Laboratory	12,840		20,212	
Total O&M Costs		$ 32,660		$ 70,243

Source: JBF estimates

- 1.0 Mgd Trickling Filter, strong influent
- 1.0 Mgd Trickling Filter, weak influent
- 1.0 Mgd Activated Sludge, weak influent

ANFLOW operation and maintenance costs were observed to be less than those for the conventional technologies in every design flow and influent quality case that was considered. Conventional technologies at the 0.05 mgd design flow incurred between 49.3% and 57.9% more operating and maintenance expenses per year than did the ANFLOW system. At the 1.0 mgd design flow rate, the conventional technologies O&M costs were greater by 43% to 57.3%. Comparisons among the three technologies are summarized in Tables 22 and 23. For these flows, ANFLOW with filtration is less expensive or comparable to conventional systems without filtration.

3. Validity Confidence

The validity of the above conclusions based on the cost data reported herein, is predicated on the following considerations:

- Preliminary treatment is required for all three technologies. It was assumed that for equal flows the costs would be the same.

- Primary and Secondary clarification were not included in the ANFLOW process design.

- Costs associated with the ANFLOW column proper are affected to a great extent by the packing medium which is selected. It was assumed that 1" ceramic Raschig rings (at $10.00/cu.ft.) would be used, based on the AWARE and the Oak Ridge reports. The packing medium accounts for more than 60% of the column cost in both design flow cases. The substitution of a less expensive medium would favorably affect ANFLOW's overall cost competitiveness.

- Filtration is required for all three technologies to reduce suspended solids to levels which meet secondary treatment standards (weak influent cases) of 15 mg/l. It was assumed that the costs were the same for each technology under a given set of design and influent criteria. Sand filtration is indicated for the ANFLOW process especially in the weak wastewater cases.

- Disinfection is required for all technologies. Costs were assumed to be equal for each technology under given design and influent criteria.

- Sludge handling expenses were reported for the conventional activated sludge and trickling filter installations. The extent of ANFLOW's sludge handling requirements is unknown, but is probably low. Therefore, no costs were reported for sludge handling in the ANFLOW process.

Table 22. Comparison of Costs for Treatment Systems, 0.05 mgd

	ANFLOW	Activated* Sludge	Trickling* Filter
Capital Cost	$601,000	$872,000	$819,000
O&M Cost	33,000	75,000	66,000
Present Value (20 yr, 6 5/8%)	969,000	1,708,000 (1,534,000 w/o filtration)	1,554,000 (1,390,000 w/o filtration)

* Average of two influent quality estimates.

Table 23. Comparison of Costs for Treatment Systems, 1 mgd

	ANFLOW	Activated* Sludge	Trickling* Filter
Capital Cost	$2,156,000	$2,012,000	$1,819,000
O&M Cost	70,000	155,000	126,000
Present Value (20 yr, 6 5/8%)	2,936,000	3,739,000 (3,337,000 w/o filtration)	3,223,000 (2,859,000 w/o filtration)

* Average of two influent quality estimates.

The above considerations which were included in this analysis are summarized in the following matrix of process design requirements:

	Activated Sludge	Trickling Filter	ANFLOW
Preliminary Treatment	X	X	X
Primary Clarification	X	X	---
Secondary Clarification	X	X	---
Pumping	X	X	X
Filtration	X	X	X
Disinfection (chlorination)	X	X	X
Sludge Handling	X	X	---

Analysis of the ANFLOW cost data suggests that substantial savings can be realized, especially in the operation and maintenance of the system. Approximately 80% of ANFLOW's total operating costs are incurred for personnel, power, and chemicals. ANFLOW capital costs are controlled to a great extent by the cost of the packing medium. Ongoing research may identify less expensive materials that can be substituted to further improve ANFLOW's economic attractiveness.

In general, the ANFLOW system appears to be less expensive to construct, maintain and operate than either of the conventional technologies. Several factors may however, adversely affect ANFLOW's competitive posture under certain circumstances:

- Colder climatic regimes may require additional excavation to bury the ANFLOW column and/or increased energy consumption for influent preheating.
- Ammonia levels in the ANFLOW effluent may be unacceptable at some locations. This may require the additional expense associated with aeration units to facilitate ammonia-stripping.

4. <u>Applicability</u>

The cost figures reported in this section do not reflect regional differences that would be encountered in the actual construction of a sewage treatment plant. The traditional method for dealing with these differences is by means of the various cost indices available through both government and private sources. In this case, the use of regional cost indices is not warranted because of the lack of precision in the cost estimates. The accuracy and adequacy of cost estimates will be greatly improved with the experience gained through large scale testing of the ANFLOW system. This will result in a more confident appraisal of the cost effectiveness of the system as compared to the conventional technologies.

F. NATIONAL SYNTHESIS

1. Municipal Wastewater Treatment

a. Approach

ANFLOW's market penetration will be governed by a great many factors, most of which can be clearly defined only after testing of larger units has been conducted. In anticipation of reliable data from larger demonstrations, certain assumptions are made to develop the municipal market size for ANFLOW and the attendant energy effects. These assumptions include:

- Successful scale-up with no major problems with hydraulic or pollutant removal performance.
- Cost-competitiveness without regard to treatment plant size. This assumption depends on lowered costs for packing material and continued inflationary increases in energy costs for aerobic systems.
- Methane production in the Oak Ridge climate applicable to all regions of the country except those whose cold climate logically precludes anaerobic treatment.

Three levels of market penetration are assessed:

- Maximum possible treatment of all municipal wastewater nationwide. Require total retrofit of all existing systems as well as use in all new construction.
- Total commitment without retrofit - assumes all new construction including expansions of existing systems, will use ANFLOW.
- New construction only - same as previous level without plant expansions.

To estimate the potential impact of ANFLOW, the energy information from Section III.D has been used. Table 24 summarizes and rearranges that information. Large conventional plants are assumed to digest sludge anaerobically, with methane collected and used. Methane generation values for these systems were based on data from Wesner, et. al.[5] Because a common rule of thumb for the BOD of domestic wastewater is 200 mg/ℓ, the methane generation potential of strong and weak influents has been averaged in this table. Because most energy used in treatment plants is electrical, the columns for treatment plant use and methane generation are shown in electrical terms. The "surplus" and "consumption" columns, because they are to be used for national synthesis (quads) have been converted back to Btu with the calculation

$$\text{Surplus } \frac{\text{Btu}}{\text{yr}} = \text{Surplus } \frac{\text{Mwh}}{\text{yr}} \div .35 \text{ electric generation efficiency}$$

$$\times\ 3415\ \frac{\text{Btu}}{\text{kWh}} \times \frac{1000\ \text{kWh}}{\text{MWh}}$$

Table 24. Balance Between Energy Use and Production for Various Treatment Systems (per mgd)

Plant Type	Total Energy Required (MWh/yr)	Electric Energy Potential of Methane (MWh/yr)*			Average Net Surplus (Btu/yr)	Average Net Consumption (Btu/yr)
		Strong	Weak	Average		
ANFLOW	238	740	200	470	7.9×10^8	---
Activated Sludge	517	390	130	260	---	2.5×10^9
Trickling Filter	307	350	120	235	---	7.1×10^8

* Assuming anaerobic sludge digestion in aerobic plants and recovery of dissolved CH_4 in ANFLOW plants.

The energy values in Table 24 will be combined with flow values to derive a national synthesis. First, however, the regional probability of ANFLOW's success (i.e. cold region performance) must be considered.

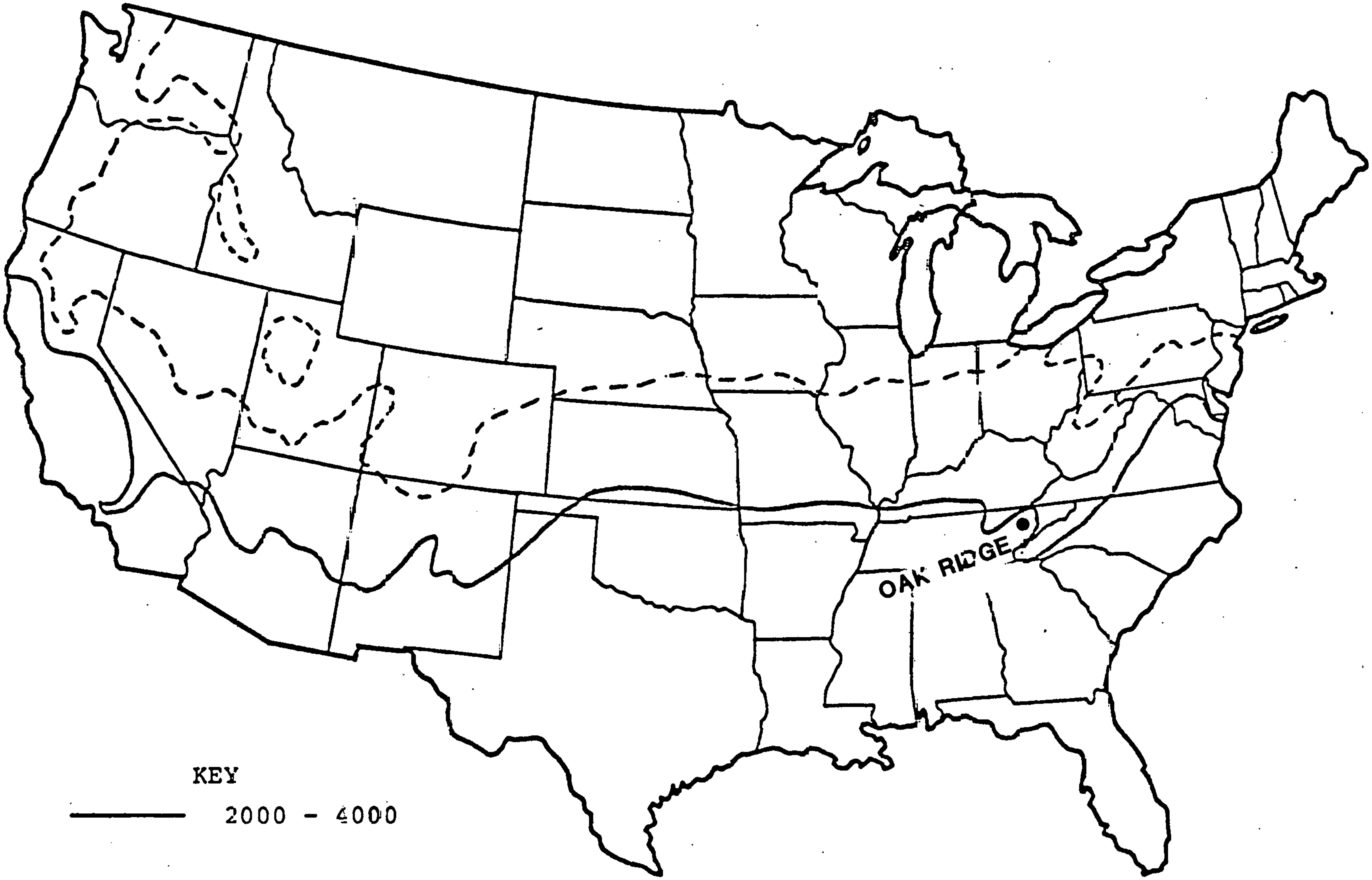
A detailed analysis was conducted to assess the number of new secondary treatment plants expected to be built in "warm" climates. Only flows up to 1 mgd were considered, but the ratio of "warm region" plants to total plants in the country should be independent of flow.

An estimate of the geographical area with suitable climatic conditions was generated from a known distribution of Mean Annual Total Heating Degree Days. States within +150 percent of the Oak Ridge Degree Day isopleth were included. This boundary is consistent with the U.S. EPA criterion of 38°N Latitude as divider between warm and cold climates.

The geographic distribution is illustrated in Figure 4. The EPA Needs Survey[10] served as the source for the actual number of new, enlarged, or enlarged and upgraded plants with a design flow of up to 1 mgd to be included for each state. States through which the 6000-degree day isopleth passes were included in the "warm" region in their entirety. The statewide totals in each size range were added, with a resultant national total of 3,700 plants of 1 mgd or less. The total of all plants in the country within this size range to be newly built, enlarged, or enlarged and upgraded is 5,700.

Based on this detailed survey of a sector of the market, the factor $\frac{3700}{5700}$ is applied to the national market size projections to reflect ANFLOW's probable lack of future use in cold regions.

Figure 4. MEAN ANNUAL TOTAL HEATING DEGREE DAYS (Base 18°C)



KEY

——— 2000 - 4000

------- 4000 - 6000

1115-2/1/80

b. New Construction Only

During the period from 1978 to 2000, more than 4000 new secondary treatment plants have been projected to be constructed in the U.S.[10]. Table 25 summarizes the total number of entirely new secondary plants which are planned to be constructed by the year 2000, by EPA Region and by plant flow ranges.

Table 25. Number of Secondary Treatment Plants to be Constructed Between 1978 and 2000

	TOTAL PROJECTED FLOW (MGD)							
EPA Region	0-.105	.106-.5019	.502-1.05	1.06-5.019	5.02-10.5	10.6-50.2	>50.2	Regional Totals
1	77	79	17	32	2	2	0	209
2	153	120	18	13	4	4	3	315
3	550	363	64	38	3	3	0	1,021
4	335	173	27	38	9	7	1	590
5	344	131	8	3	0	2	0	488
6	182	69	10	10	2	2	1	276
7	665	27	4	10	3	3	0	712
8	216	6	2	5	3	1	0	233
9	65	50	10	13	3	5	1	147
10	197	59	7	8	2	1	0	274
U.S. Totals	2,784	1,077	167	170	31	30	6	4,265

Source: Reference 10

The total flows within each flow range were converted to energy effects by the following sequence:

a. Use the midpoint of each flow range to represent that group.

b. Multiply total number of plants in flow range by midpoint flow to find national flow for that flow range.

c. For each flow range, multiply total national flow by energy surplus/consumption values from Table 24.

d. Multiply by $\frac{3700}{5700}$ to account for cold region problems with anaerobic processes.

The results are shown in Table 26. Relative to trickling filter plants, the annual national energy benefit from ANFLOW's exclusive use would be 3.2×10^{12} Btu/yr (0.003 quads). Relative to activated sludge, the value would be 6.5×10^{12} Btu/yr (0.006 quads).

c. Total Commitment Without Retrofit

Using an approach similar to that described above, the 1978 Needs Survey was consulted to determine the number of new and enlarged plants projected to be built by the year 2000. In the interest of brevity, the breakdowns are not presented as in Tables 25 and 26, which were shown to illustrate the computation procedure. Totals for each flow range are, however, tabulated in Table 27. At this higher level of commitment where all plant expansions use ANFLOW, the national energy benefit relative to trickling filter plants would be 5×10^{12} Btu (0.005 quads). Relative to activated sludge, the benefit would be 0.01 quads.

d. Maximum Possible Commitment

If a national commitment to ANFLOW included retrofit of all existing systems within the warmer regions of the country, the energy benefits shown in Table 28 would be expected. At this level of commitment, however, the energy required to build the facilities may seriously reduce these advantages. Throughout the analysis to this point, it has been implicitly assumed that energy inputs for the construction or expansion of facilities would be roughly equivalent among the three candidate systems. When a retrofit of an in-place system is done, that assumption is clearly invalid.

Because derivation of energy inputs for ANFLOW retrofits is beyond the scope of this task and would be based on very sketchy data, quantitation of these inputs is not presented. The values in Table 28 must be viewed for now as optimistic.

2. Industrial Wastewater Treatment

No tests with ANFLOW columns have been conducted on industrial wastewaters, and therefore assessments of the process's potential in the industrial market are tenuous. It is useful, however, to make some assumptions about ANFLOW's probable performance on selected industrial wastes and thereby derive rough estimates of its potential energy benefits.

The industrial wastewater treatment market has no such convenient summaries as the EPA Needs Survey for municipal wastewater. National summaries on specific industries are available in scattered references, and these have been consulted.

Table 26. Estimates of ANFLOW's Total Energy Benefits for Secondary Treatment Plants Projected to be Built by the Year 2000*

(10^9 Btu/yr)

Process	FLOW RANGE (MGD) 0–.105	.106–.5019	.502–1.05	1.06–5.019	5.02–10.5	10.6–50.2	>50.2	Totals
Activated Sludge	(734)*	(1644)	(649)	(2595)	(600)	(2280)	(1125)	(9627)
Trickling Filter	(442)	(991)	(392)	(1562)	(170)	(648)	(320)	(4525)
ANFLOW	(338)	(756)	51	204	190	721	356	447
Net Benefit** of ANFLOW Relative to:								
Trickling Filter	104	235	443	1766	360	1369	676	4953
Activated Sludge	396	888	700	2799	790	3001	1481	10,055
Net Benefit within only those regions (warmer) where ANFLOW can be expected to succeed. Relative to:								
Trickling Filter	68	153	288	1146	234	889	439	3217
Activated Sludge	241	576	454	1817	513	1948	961	6510

* Values are Total National Energy Surplus (consumption) if all plants use that treatment process.

** These two rows are national totals before application of the factor to account for anaerobic processes' poor performance in cold climates.

For conventional plants up to 5.019 mgd, no methane generation was assumed. Larger conventional plants were assumed to generate methane. ANFLOW plants up to 0.5 mgd were assumed not to recover and use methane.

Table 27. Estimates of ANFLOW's Total Energy Benefits for All Treatment Plants Projected to be Built or Expanded by the Year 2000

(10^9 Btu/yr)

	FLOW RANGE (MGD)							
	0–.105	.106–.5019	.502–1.05	1.06–5.019	5.02–10.5	10.6–50.2	>50.2	Totals
Net Benefit Relative to:								
Trickling Filter	77	199	452	1983	393	1484	659	5247
Activated Sludge	272	749	712	3143	862	3254	1442	10,434

Table 28. Estimates of ANFLOW's Total Energy Benefits for All Secondary Treatment Plants, Including Retrofits, Projected to Exist in the Year 2000

(10^9 Btu/yr)

	FLOW RANGE (MGD)					
	0–0.105	0.106–1.05	1.06–10.5	10.6–50.2	>50.2	Total
Net Benefit Relative To:						
Trickling Filter	341	2205	15,180	8446	5576	31,748
Activated Sludge	1210	5150	25,630	18,507	12,205	62,702

Industries for which information is readily available on national BOD generation include meat packing, dairy products, pharmaceuticals, textiles, and organic chemicals. These industries are assessed here because they generate large quantities of BOD and usually use conventional biological treatment system to meet discharge requirements.

Assumptions used in the analysis include:

- BOD concentrations similar to TOC.
- Methane generation with ANFLOW = 7.2 scf/lb BOD entering the system (derived in Section III.E).
- Energy consumption per pound of BOD entering the system similar to that for municipal wastes for all treatment systems.
- Fuel value of electricity computed at 35 percent conversion efficiency (9,757 Btu/kWh).
- In the absence of reliable data on existing facilities vs. new construction needs, assume the ratio to be similar to that for the municipal sector.

Table 29 presents the projected energy effects of ANFLOW systems in selected industries. Assumptions and references not listed above are given on the table. Comparison with Tables 25-28 shows that projected energy benefits are of the same order of magnitude as for the municipal sector.

3. Summary

The foregoing computations and projections do not say that a national commitment to ANFLOW will achieve the tabulated energy benefits. The figures merely point out the potential, assuming that the required extensive scale-up and development reveal no major impediments to wide-scale use of the process in the field. Some presently unquantified issues relating to ANFLOW's future use are discussed in the next section.

Table 29. Projected Energy Effects of ANFLOW Use in Selected Industries for Year 2000

Industry	Annual BOD Load ($x10^6$ lb/yr)	Energy Consumption by Aerobic Systems[a] ($x10^{12}$ Btu/yr)	Energy Consumption by ANFLOW Systems[b] ($x10^{12}$ Btu/yr)	Methane Generated by ANFLOW Systems ($x10^{12}$ Btu/yr)	Net National Annual Energy Benefit from ANFLOW: Total Including Retrofit ($x10^{12}$ Btu/yr)	Net National Annual Energy Benefit from ANFLOW: New Construction Only[c] ($x10^{12}$ Btu/yr)
Meat Packing	300[d]	1.4	0.7	2.2	3.1	0.32
Dairy	500[d]	2.2	1.1	3.6	5.0	0.51
Pharmaceutical	79[e]	0.3	0.15	0.51	0.71	0.08
Textile	1764[e]	7.7	3.9	12.7	17.7	1.9
Organic Chemical	756[e]	3.3	1.7	5.4	7.6	0.8

a. Assuming 0.45 kWh/lb BOD entering plant (calculated assuming consumption of 1-mgd aerobic plant at 412 MWh/yr).

b. Assuming ANFLOW energy consumption at half that for aerobic systems (see Tables 6 and 7).

c. Assuming new construction: total need ratio same as that for municipal sector (from Tables 23 and 25, this ratio is 0.106).

d. Values cited in letter, C. Scott (ORNL) to A. Haynes (DOE), March 23, 1979.

e. JBF estimate based on raw data in Ref. 11 (Pharmaceuticals), 12 (Textiles), 13 (Organic Chemicals).

IV. ASSESSMENT OF THE TECHNOLOGY

A. INTRODUCTION

An evaluation of the future usefulness of a wastewater treatment technology must be concerned with that technology's:

- o state of technical development;
- o advantages and disadvantages vis-a-vis alternate methods;
- o status in terms of federal regulations; and
- o probable deployment characteristics.

The following section addresses these issues.

B. STATE OF TECHNICAL DEVELOPMENT

The ANFLOW process has been tested on one real waste stream: the municipal influent to the Oak Ridge East Treatment Plant. This limited experience and the scale of the pilot plant leave many questions about process performance that can only be answered by exposure of the system to other wastes, at larger scale. ORNL's plans to construct a 50,000-gpd demonstration in Knoxville, as well as their planned bench-scale experiments on many questions of toxicity, ammonia, and temperature effects, are appropriate paths to follow in advancing knowledge about the technology. To a large extent, many of the uncertainties identified previously and summarized below should be clarified by ORNL's continuing efforts.

1. Achieving Discharge Requirements

ANFLOW columns followed by granular media filtration should meet secondary treatment standards for most municipal effluents. Some question remains as to whether the soluble BOD in ANFLOW effluents may require an adsorptive or oxidative upgrading process to meet standards at sites with a discharge limit of less than 15 to 20 mg/ℓ BOD.

The process's stability toward toxic substances, pH excursions, and organic shock loads in the column feed is not well understood. Anaerobic systems are generally regarded as more sensitive to these challenges than aerobic systems (with the exception of organic shock loads). Thus, the burden of proof is upon the proponents of ANFLOW to convince the profession of the process's stability. Similarly, anaerobic systems are known to perform poorly in cold weather. Refined assessments of the process's regional applicability must await more experience at low operating temperatures.

In addition to investigating the process's stability toward toxic substances, it should be compared experimentally to aerobic systems as to the pathways and transformations that occur to toxic substances in the reactor. Resolution of this question will guide sludge management options and will help to define effluent effects in receiving waters.

2. Energy Conservation

Little doubt remains that, if ANFLOW can be demonstrated further as an effective waste treatment process, it will save considerable energy relative to conventional aerobic processes. A critical unknown in quantitating the energy saving is the solids quantity and quality that will be blown down from ANFLOW columns. Further demonstrations should answer this question.

Another uncertainty is in the pumping energy required to lift the wastewater through full-scale columns. Scale-up demonstrations should seek to minimize the pumping head, consistent with effective process performance.

3. Methane Generation

Many questions remain to be resolved regarding methane generation, including:

a. Can equipment be made available at reasonable cost and efficiency, to recover the significant quantities of methane dissolved in the reactor effluent?

b. Will equipment be available at reasonable cost to collect, clean, store, and use methane in the smaller plants where ANFLOW is most economically competitive?

c. Again with regard to smaller plants (less than 1 mgd): how can surplus offgas be marketed and used? Small plants are usually in small communities. Use of surplus offgas would require an extensive system to transport small volumes of gas from dispersed sources to users of the offgas (or, alternatively to regional processing facilities that could upgrade it for injection into natural gas pipelines).

4. Proprietary Concepts

No patents have been issued related to the ANFLOW process. ORNL investigators have mentioned the packing material and the microbial community as possible proprietary concepts.

C. ADVANTAGES AND DISADVANTAGES

The tabulation on this question in the AWARE report (shown herein as Table 1) covers the most important differences. It should be emphasized, however, that that table is based on an assumed future date when the many questions about ANFLOW have been resolved. The most severe "disadvantage" to ANFLOW compared to aerobic systems is the need to expand the knowledge of the process. In one sense, however, this is a near-term advantage, in that the need to prove the process should qualify it for preferential funding by the EPA Construction Grants Program as an "Innovative Technology". This issue is discussed below.

D. REGULATORY CONSIDERATIONS

Effluent limitations for publicly owned treatment works (POTW's) and industrial dischargers were prescribed in the Federal Water Pollution Control Act

(FWPCA) of 1972. In 1977, the Act was amended by the provisions of the Clean Water Act (CWA), which provided for extensions of the earlier deadlines for secondary treatment due to lack of funding, delayed completion, etc. Waste management techniques which result in the use of Best Practicable Waste Treatment Technology (BPWTT) are now required by July, 1983. The definition of "secondary treatment" was published on August 17, 1973, in 40 CFR 133. These final regulations established effluent levels for biochemical oxygen demand (BOD_5), Suspended Solids (SS), coliform bacteria, and pH. The ANFLOW process with filtration has demonstrated a potential for meeting the effluent limitations for these parameters and should, therefore, be considered an adequate technology for the attainment of secondary treatment objectives under some range of operating conditions.

Locally applicable water quality criteria may be, however, more stringent than those prescribed in the FWPCA. This situation arises as the result of:

- EPA Approved Water Quality Plans
- State Court Orders
- Federal Court Orders
- Discharge Permit Conditions
- State or Federal Enforcement Orders
- Voluntary Compliance
- State Certificate
- Other

Conditions which warrant one or more of the above actions are caused by unusually high levels of toxic substances, organics, or nutrients. Where additional (tertiary) treatment is required, additional expense is incurred which potentially affects the cost competitiveness of the ANFLOW process.

Legislative cost considerations are dealt with in the "Innovative and Alternative" (I and A) technology guidelines which were published in FR Vol. 43, No. 188, September 27, 1978. These guidelines delineate the criteria for designation as an I or A technology. It is a distinct advantage to be classified as either an "Innovative" or "Alternative" technology (by the EPA Regional Administrators) because an additional 10 percent of the construction costs will be paid by EPA under the Construction Grants Program. In addditon to the 85 percent funding level for I and A technologies, a full (100 percent) reimbursement is guaranteed should the technology fail. The guidelines define "Alternative" processes as those that are:

> ". . . proven methods which provide for the reclaiming and reuse of water, productively recycle wastewater constituents or otherwise eliminate the discharge of pollutants, or recover energy."

These methods include unconventional effluent treatment technologies such as land application, aquifer recharge; aquaculture; silviculture; and, direct reuse for nonpotable purposes. "Innovative" processes are defined as:

> ". . . developed methods which have not been fully proven under the circumstances of their contemplated use and which represent a significant advancement over the state of the art in terms of . . . cost reduction, increased energy conservation or recovery, greater recycling and

conservation of water resources, reclamation or reuse of effluents and resources, improved efficiency and/or reliability, the beneficial use of sludges or effluent constituents, better management of toxic materials, or increased environmental benefit."

Treatment processes based on conventional concepts of treatment (e.g., biological or physical/chemical) are not considered innovative except where it meets either of criteria a) or b) below. An "Alternative" technology can be deemed "Innovative" if it meets any of the following six criteria:

a) have a life-cycle cost at least 15 percent less than that for the most cost effective alternative;

b) offer at least 20 percent net primary operating energy savings over the least net energy alternative;

c) improve the operational reliability of the treatment works in terms of upsets, discharges, and operator skills;

d) provide better management of toxic materials;

e) result in increased environmental benefits; and,

f) provide new or improved methods of joint treatment of municipal and industrial wastes.

The 15 percent cost and 20 percent energy criteria (a) and b) above), have been interpreted for new plant construction and the upgrading of an existing plant. Either criterion must be met based on total plant cost- or energy-savings for a new plant. The criterion must be met based on the new portion cost- or energy-savings for an upgraded plant.

The ANFLOW process has the potential to qualify as an innovative technology on both its cost- and energy-savings merits for a number of applications in several EPA regions.

E. PROBABLE DEPLOYMENT CHARACTERISTICS

1. Type of Deployment

This study, and those by ORNL, have shown that ANFLOW's primary economic advantages are at low flow rates. At plant capacities between 1 and 10 mgd, economies of scale in conventional systems make them more attractive from a capital cost standpoint. If the cost of packing material can be reduced, however, ANFLOW's capital cost would become competitive at higher design flows. Assuming that this cost reduction can be achieved, the life-cycle costs of ANFLOW are expected to be competitive at higher flows. A proven, mature ANFLOW technology would then be most advantageous under the following conditions:

- Influents high in degradable organics - especially treating wastes from industries that can use the surplus offgas directly

- Sites near potential customers that can purchase the surplus offgas
- In warm climates

The question of scale is difficult to resolve. Small communities would find the energy savings and process simplicity attractive, but may forego offgas use because such use detracts from that simplicity. In addition, surplus offgas may not have a convenient market in small communities.

Larger plants can use and probably sell excess offgas, but the cost question awaits resolution of the mature product cost for packing materials.

2. Scale of Deployment

The national energy projections in Section III are based on optimistic assumptions of wide-scale deployment. The scale of deployment may be limited by the findings of further testing on the process. In particular, process sensitivity to toxic substances or pH variations may hinder its application in publicly owned treatment works (POTW's) with a significant industrial component of flow. This possibility may be set aside by further testing on the process, but is based on the operational problems frequently encountered in anaerobic sludge digesters.

If industrial flows are shown to hinder ANFLOW's use, estimates of the extent of industrial contributions will be useful. These have been derived from the Needs Survey[10]. For the year 2000, 21.5 percent of POTW's are projected to receive industrial flows, with the national fraction of flow contributed to POTW's by industry projected at 16.5 percent. Approximately half of the POTW's treating industrial flows will have design capacities above 10 mgd. Therefore, sensitivity to industrial wastewaters could limit ANFLOW's "across the board" market penetration by up to approximately 20 percent. This is a worst case estimate, of course, because many industrial components (e.g. food processing) would not contain toxic or inhibitory fractions.

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