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HYMETH Process

High-purity Methane from Wastes

ERA, Inc.

1638 Main

Lubbock, Tx.



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I. INTRODUCTION

The energy "crunch" is being felt world-wide. Our nation is feeling the full impact of the problem for the first time. Conservation measures are very helpful in minimizing the shortage. Expansion of the production of fossil fuels will also help. Technology to increase the use of coal (such as gasification, desulfurization etc.) will also be an important response. In the long run however, there is a need to deter from the consumption of nonreplacable fossil fuels merely for the production of energy. There are several optional sources of energy that are non-depleting and development of these sources is mandatory if civilization is to continue indefinitely on a high energy diet. This proposal considers the most logical option : That of turning a liability and resource consumer into an asset or energy and resource producer. None of the other options such as solar, geothermal or wind energy can make such a contribution. In addition none of the other options have such extensive history, technical background or operating experience that would allow rapid large-scale application.



II. BACKGROUND

A. Waste Resources

Perhaps the most striking aspect of the entire NASA aerospace exploration effort to the general public was the sudden realization of the fragility, beauty and uniqueness of the earth as seen in photographs from outer space. Certainly there is no other planet like it in this solar system, and perhaps not even in our galaxy. As British author and lecturer, Barbara Ward, has pointed out, aerospace developments have given us a view of the world as "Spaceship Earth," a relatively tiny planet with a delicate and perhaps unique ecological balance. The clear implication is that we had better look after it, as there may be nowhere else for mankind to go.

At the present time the industrial nations of the earth are using up irreplaceable natural resources such as our fossil fuels at accelerating rates, and the underdeveloped nations are redoubling their efforts to catch up. The world's population will approximately double by the year 2,000 adding to the drain on natural resources, and producing pollutants at a vastly greater rate. There is no hope of maintaining present living standards and the quality of life without drastic changes in our way of handling our resources as well as our wastes.

Athelstan Spilhaus pointed out many years ago that "a pollutant is a misplaced resource." One way of handling pollution, therefore, is to discover ways in which to capture and reuse these misplaced resources.

The space capsule used for an extended journey through space constitutes a closed ecological system. Phillips¹ has described how all waste products, including urine and fecal material, must be recycled and reused by the astronauts. Thus, during the 1950's and early 1960's NASA sponsored a great many research projects in which every conceivable method for accomplishing this purpose was intensively investigated. Significant progress was made in university laboratories, industrial research laboratories, and in NASA's own research centers. A great deal of information potentially useful in both the public and private sectors of the U.S. economy was thereby generated. Indeed, many of these deve-

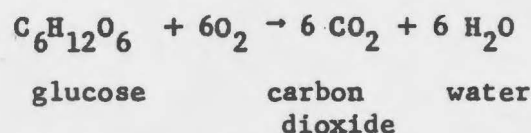


lopments have already found successful applications.

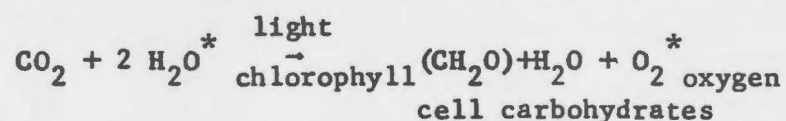
Here, however, we are concerned only with aerospace technology developments which can be applied to problems of water pollution and solid waste management in the public sector. The physical and physico-chemical methods which were investigated by NASA for the disposal and recycling of human wastes, including pyrolysis, incineration, oxidation and reduction by means of strong chemical reagents, electrolysis and distillation have found only small-scale limited applications because of their relatively high cost. The biological methods, in contrast, are much more economical, and have thus found important applications in the treatment of sewage and industrial wastes. Bogan and Chapman² of the Boeing Co. carried out intensive studies on the development of a miniaturized microbial waste disposal system for confined space operation. During the course of this work an aerobic stirred-reactor activated-sludge system was developed which decomposed human wastes at rates hundreds of times as fast as conventional municipal sewage systems by means of bacteria in a highly concentrated medium. Lessons learned in this research led to the development of modern "packaged" activated sludge treatment plants for individual homes, small developments, or ships at sea, which are now on the market. Cody and Tischer³ showed that potential food material could be made by growing certain fungi on human wastes. Gray⁴ extended this work to many other waste products, and showed that a wide variety of agricultural wastes could be converted to potential animal feed by fungi. Church et al.^{5,6} further refined the process into an economical continuous process for converting liquid food-processing wastes from corn wet-milling, soybean processing and corn- and pea-canning into fungus mycelium. Chemical analysis and rat-feeding studies showed the material to be a nutritious high-protein feed. Furthermore it could be produced in a simple non-aseptic continuous fermentation, and the fungi could be easily recovered by coarse filtration. Thus the process should be more economical than the use of yeasts, as advocated by Meller⁷, or bacteria as advocated by Callihan and Dunlap⁸. Updegraff⁹

developed a process for converting waste paper (which comprises more than 50% of municipal solid wastes) into fungus mycelium, and Updegraff et al.¹⁰ applied a non-aseptic fungus fermentation system similar to that used by Church et al. for corn and soybean wastes to convert coffee-processing wastes and "spent wash" from a rum-distilling plant into fungus mycelium.

All of this work was concentrated on converting the organic material back into potential food material. Other work sponsored by NASA employing algae in the photosynthetic reaction, was carried out to recover the oxygen consumed by the respiration of both men and the bacteria and fungi used to reconvert the organic wastes. In respiration reactions organic compounds are oxidized to provide energy. The aerobic oxidation of glucose proceeds according to the following process:



There is no known biological reaction for recovering the oxygen from the carbon dioxide, but it can be recovered from the water by the photosynthetic reaction, according to the following equation:

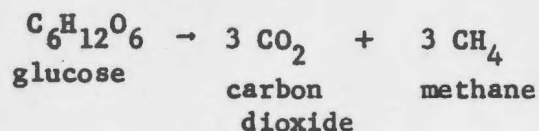


Experiments with isotopically labelled carbon dioxide and water have shown that the oxygen comes only from the water.

Thus, in the closed ecological system of a space ship organic wastes could be completely recycled by aerobic microbiological breakdown of the wastes to CO_2 and minerals (nitrate, phosphate, sulfate and others) which would then be consumed by algae resulting in oxygen production and production of algal biomass utilizable as food. All that this cycle requires is that the waste material must be completely biodegradable by the microorganisms. Ort¹¹ and Oswald¹² have developed commercially practical methods of using this cycle in treating sewage and industrial wastes to recover pure water and a high protein by-product.



Another way of recycling organic wastes is by means of anaerobic microbial degradation using the methane fermentation. This system converts organic materials into a mixture of carbon dioxide, water and methane by means of a mixed bacterial flora. Buswell¹³ has shown that almost any organic material may be converted nearly quantitatively into these products as described in the equation below for glucose:



Note that the reaction depicted with glucose produces equal volumes of carbon dioxide and methane. Many other substrates result in the production of twice as much methane as carbon dioxide.

The carbon dioxide may be removed by scrubbing with water or alkali, leaving methane, a high energy-yield fuel. The use of methane as a fuel leads to carbon dioxide and water and consumes oxygen. Again the oxygen may be regenerated from water by the photosynthetic reaction using algae, and the algae used as food. Thus, by means of this reaction sequence both energy and food may be recovered from wastes. Such a system appears particularly attractive at this time in the United States, as supplies of natural gas are declining, and we have enormous amounts of sewage sludge, municipal solid wastes, and agricultural wastes to dispose of. As Barker¹⁴ has pointed out, almost any organic material except for hydrocarbons or lignin can be almost quantitatively converted to methane and carbon dioxide by this process. Buswell's extensive investigations have established an average composition for the produced gas of 70% methane and 30% carbon dioxide¹⁵.

Only references 1,2,3,4, and 10 reported research sponsored by NASA, but nearly all of the other work cited may be regarded as based on principles clearly brought out by the earlier NASA-sponsored work.

Heden¹⁶ has described the use of aerospace microbiology for terrestrial purposes, emphasizing the need for reclamation of waste materials



and efficient disposal of effluents to abate the air and water pollution. Bendersky and Winfrey¹⁷ have analyzed water pollution and related public health problems, and attempted to identify aerospace-generated-technology which could be applied to their solution. This proposal represents just such an effort applied to sewage, agricultural wastes and municipal solid wastes.

B. Biological Waste Treatment

The biological treatment of wastes goes back to antiquity, but it is only in the twentieth century that the organisms and processes have been elucidated. Composting, an aerobic microbiological process for converting solid cellulosic wastes into a material with soil-conditioning and fertilizer value was undoubtedly practiced by prehistoric animal herders¹⁸. It is widely used today, principally in Europe, for the conversion of municipal solid wastes and agricultural wastes. It is not widely used at the present time in the U.S. because inorganic fertilizer is more economical to apply.

The treatment of liquid wastes, including sewage and industrial wastes, is a relatively new development in the United States. Until 1965 less than half of the U.S. sewage received any treatment, and even a smaller percentage of industrial wastes was treated. These materials were simply dumped into the nearest water courses, resulting in massive water pollution.

The recent trend toward concentrated animal feedlots, particularly for cattle, hogs and chickens, has also resulted in the accumulation of astronomical amounts of manure. The market for this manure is very limited, because it is more economical to apply inorganic fertilizer. Thus runoff from these accumulations of feedlot wastes is now a major source of water pollution. Loehr¹⁹ points out that livestock produced about 2 billion tons of manure each year in the U.S. during the years 1963 to 1968. The amount is larger now, and steadily increasing.

Most rivers, estuaries and harbors in the United States are heavily polluted with industrial wastes and sewage which have received little or no



treatment. Floating debris of all kinds, including human excrement and garbage, may ordinarily be seen. The water is dark and foul with chemical pollutants, and teeming with bacteria and viruses, including human pathogens.¹⁰ This situation is due primarily to the emptying of raw sewage and wastes from land based cities and industries. Ships contribute only a small fraction of the total load.

New York is perhaps the worst example in the U.S. of ocean pollution. Twenty miles southeast of Manhattan is the repository for the city's garbage and sewage sludge. A 20 square mile area there is virtually devoid of all life except for microbes.²⁰

The need for cleanup and pollution prevention on a massive scale is now generally recognized. The cost will be large, but improvements are coming, forced by State and Federal legislation.

Biological treatment of sewage and liquid industrial wastes may be primary treatment only, which consists merely of screening or gravity settling to remove the larger solid particles, or of primary and secondary treatment. Secondary treatment consists of a microbial digestion process, in which bacteria and fungi digest and remove a large fraction of the organic materials in the water. The effluent from secondary treatment may then be chlorinated, if desired, to kill all pathogenic bacteria, or it may be subjected to tertiary treatment for additional purification. Tertiary treatment processes include biological extended-aeration processes to remove more organic matter and convert all nitrogen compounds to nitrate, biological denitrification, an anaerobic process in which nitrate is removed as nitrogen gas, activated carbon treatment and reverse osmosis treatment. Using these processes, followed by chlorination, sewage can be converted into pure water suitable for drinking water.²¹

Biological treatment systems may be divided into two general types, aerobic systems and anaerobic systems. Aerobic systems employ forced aeration by means of compressed air or oxygen in order to oxidize the organic matter, by means of an activated sludge of bacteria and fungi.²² Anaerobic systems operate without the presence of oxygen, and the anaerobic bacteria present convert organic wastes into a mixture of methane and carbon dioxide.²³ Each system has its advantages and disadvantages.



Aerobic systems are more widely used in the treatment of municipal sewage than anaerobic systems. They are better understood than anaerobic systems, and are capable of producing a higher quality effluent with a given digestion time.²² Aerobic systems are more effective in reducing BOD to near zero levels, while anaerobic systems rarely produce effluents below 50 mg/l of biochemical oxygen demand (BOD).²³ Aerobic systems are therefore more applicable to dilute wastes, such as domestic municipal sewage plants where the initial BOD level is from 100 to 300 mg/l. More concentrated wastes may often be treated more successfully with anaerobic systems. Anaerobic processes have the advantages of no aeration requirement, a lower requirement for nitrogen and phosphorous and a much lower production of microbial sludge.^{24,25} Thus, sludge disposal problems are minimized, and power requirements are less. Also the anaerobic process produces a useful fuel material, methane.

The simplest and cheapest waste treatment system is the septic tank. This system will accept domestic sewage, ground up garbage, and most naturally occurring wastes, and will decompose up to 95 percent of the organic materials present to carbon dioxide and methane. This system, depicted in Figure 1, requires no air compressors, pumps or moving parts of any kind. Optimum conditions for biological stabilization cannot be obtained in such a system, however, and both liquid and solid retention times must be very long, of the order of 20 to 30 days.²³ Three more advanced anaerobic digestion systems, the two stage mixed reactor and settler, the two stage with sludge return and the anaerobic filter are also diagrammed in Figure 1.

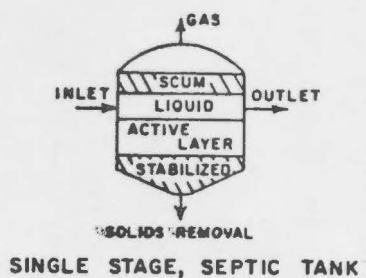
The value of mixing is indicated by the finding that 85 percent BOD reduction of a waste was obtained in less than 3 days vs 25 days in an ordinary single stage unmixed system.²³

The anaerobic digestion process depends upon a complex mixed flora of anaerobic bacteria, including two general types, the acid-forming bacteria and the methane-forming bacteria. It takes some time, days or even weeks, to accumulate the necessary bacterial flora in a new digester. Once this has been achieved, the digester will ordinarily continue to function smoothly as long as the waste is fed in at the proper rate.²⁵

Anaerobic treatment systems are sensitive to temperature variations; they operate at any temperature from 0 to 55°C. Rates are much higher at the higher temperatures. However, once a culture has been acclimated to a given temperature a sudden change of as little as

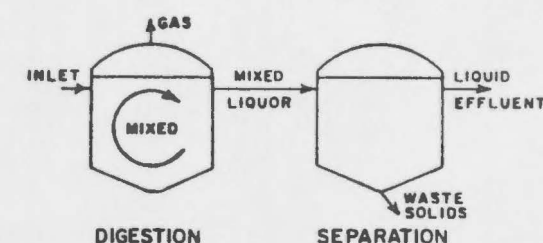


Figure 1 Anaerobic Processes



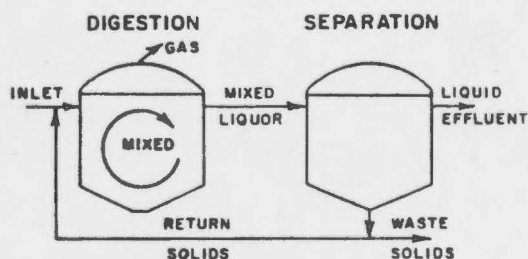
SINGLE STAGE, SEPTIC TANK

Single Stage, Septic Tank



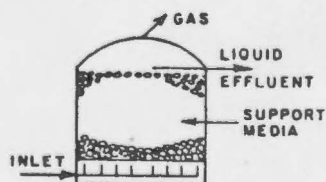
TWO STAGE, MIXED REACTOR AND SETTLER

Two Stage Mixed Reactor and Settler



TWO STAGE WITH SLUDGE RETURN

Two Stage With Sludge Return



ANAEROBIC FILTER

Anaerobic Filter



one or two degrees may interrupt the fermentation with accumulation of fatty acids.¹⁴ High concentrations of sulfides are toxic to methane-producing bacteria, as are heavy metal ions such as copper, zinc and nickel. However, the heavy metals are readily detoxified by sulfide, and hence small amounts of sulfide (< 200 mg/l) may be beneficial to the system. Sulfide may be produced from proteins by the action of proteolytic anaerobes or from sulfate by sulfate-reducing bacteria.²⁵

McCarty²⁴ has studied the kinetics of anaerobic digestion processes, and has defined the biological solids retention time (SRT) as a most important parameter:

$$SRT = \frac{M}{\Delta M / \Delta t} = \frac{\text{Suspended Solids in System}}{\text{Suspended Solids Removed per Day}}$$

By employing sludge recycle, the desired long SRT may be obtained, with a resulting increase in the effectiveness of treatment. For example, Schroepfer et al.,²⁶ were able to obtain better than 90 percent reduction in the BOD of packinghouse waste with an initial BOD of 1400 mg/l. The liquid retention time was 12 to 13 hours, and the sludge retention time (SRT) was 10-15 days. The BOD loading of the system was 156 lbs/day/1000 cu ft, or 0.16 lbs volatile solids/cu ft/day.

Buswell^{14,15} has described the general operating conditions and procedures for using the methane fermentation in practical waste disposal systems. The method finds its greatest economy with 1 to 3 percent digestible solids. Determinations should be made of organic matter or COD, of pH and of total volatile acids. In starting the fermentation, the initial load must not exceed one tenth of the anticipated final load. This load is increased by 50 to 100 percent per day with daily determination of volatile acids. If volatile acids begin to increase rapidly, the rate of feed must be decreased. The rate of feed which results in a relatively constant volatile acid content below 2000 ppm is considered a safe continuous load. Temperature must be kept constant within 1 or 2 C., and the reactor must be mixed. When these precautions are taken, it is possible to load tanks with as much as 16 kg/cu meter/day (1 lb/cu ft/day).¹³



III Hereford Plant Concepts and Objectives

The basic technology of anaerobic digestion is well-grounded upon extensive experience in the operation of municipal waste treatment plants. Comparable results have been obtained by various researchers^{27, 28} on other organic materials including beef cattle wastes on small scale tests. What remains to be determined, is precise engineering data upon which to base future commercial methane production facilities.

Data which needs to be developed includes the following:

(1) Optimum sludge consistency -- There is a range of moisture content within which digestion efficiency is greatest. Based upon experience by other researchers on bench scale beef cattle waste tests, the upper limits may be as much as 15% solids content.^{9, 28} Other considerations in addition to efficiency of digestion include handling ease, heat transfer, and water consumption. The most efficient consistency for digestion may not be the most economical in terms of water usage and the allied problem of wastewater disposal.

(2) Water recirculation rates -- Ideally anaerobic digestion may be carried out using recycle of sludge to obtain long solids retention times (i.e. 10 days) and liquid times of only 12 hours.²⁶ This operating regime may well be possible, providing the accumulation of inhibiting ions such as ammonium or sodium does not become excessive.^{29, 30} If build-up on such ions is excessive, recirculation rates on water will have to be reduced. This will mean that larger quantities of fresh water will be consumed by the operation and larger quantities of wastewater will be produced. A recirculation rate of 75% would be satisfactory although a rate as low as 50% would be acceptable.



(3) Digested sludge characteristics -- The nitrogen content of digested sludge may vary considerably. Higher nitrogen content enhances the potential value of sludge as a by-product, either for use as a soil conditioner or as a protein feed supplement. Feedlot wastes from beef cattle normally run somewhat higher in nitrogen content than manure from such sources as dairy cattle or sheep. This is primarily due to the high protein level of rations in feedlots. As a result digested beef manure sludges will run high in nitrogen and with recirculation of ammonia-bearing water (below the toxicity level, of course), a final sludge with a nitrogen content in excess of 5% should be possible. Anthony³¹ at Auburn University has produced sludges with 7% nitrogen by introducing ammonia to the fermentation process. The production of sludge with economic value can greatly improve process economics.

(4) Proprietary methods of high-purity methane production -- The methane content of gas produced by anaerobic digestion may vary widely depending upon the composition and concentration of the substrata in which the digestion occurs. Other factors also have a bearing upon the purity of methane produced. ERA has a proprietary method of producing methane of high purity from anaerobic digestion. Commercial scale evaluation of this method will be afforded by this initial commercial plant. The ERA technology will also tend to increase methane production as well as purity. This method of digestion will greatly improve the economics of methane production by obviating the need for scrubbing of the acid gas which normally accompanies methane production.



As soon as the operating characteristics of the initial plant are satisfactorily evaluated, construction of additional commercial units can commence. Contracts for sludge and gas will be readily forthcoming and relief for the energy crisis can be achieved without additional government funding in this area.



IV. Hereford Operational Plan

The Hereford plant configuration is indicated in Figure 2. Dry feedlot waste will initially be processed through a hammermill, diluted with a combination of sewage water and recycled oxidation pond water and mixed with thickened recycle sludge in the dilution tank. From the tank the diluted material will be fed into the first stage (primary) digester for approximately five days detention; then into a second stage digester for five additional days. Sludge will presumably be fed and withdrawn at least continuously to provide a efficient, smooth operation. From the digesters, sludge will be processed through a flotation thickener. Such a thickener has two distinct advantages over a gravity thickener: (1) It will produce a sludge of maximum solids content which is still fluid and (2) it produces a sludge which dewateres very rapidly because of the excellent drainability characteristics imparted by entrapped air.

A portion of the thickened sludge will be recycled to the dilution tank. The remainder will be applied to stabilized dewatering beds. The underflow water from the thickener, plus any run-off from the dewatering beds, will enter an oxidation pond. Ammonia appears to be the limiting factor in water recycle and reuse in such a system.²⁹ Experience has shown that ammonia reductions in excess of 75 percent are readily achieved in oxidation ponds. In this way perhaps 75 percent of water requirements may be met by recycling. Wastewater produced by this process would be approximately 49 gallons per minute based on the above assumptions.

The sludge residue will then be available after being dewatered to 35 to 40 percent moisture for final drying and packaging for marketing.



The cost of the 2.8 million cubic foot plant is expected to amount to about \$2,500,000 as shown in Table I. Operating costs will amount to approximately \$486,000 for one years operation, exclusive of manure and amortization costs. Table II lists the various cost factors.

TABLE I

Capital Cost Analysis on 2.8 Million Cubic Foot Design

1. Blender	36,000 gallon basin 30 ton/hour Shredder 750 gpm Pump @ 15 psi	\$203,000
2. Heaters	15 Million BTU's/hour	280,000
3. Digesters	Tanks Gas Mixers	1,176,000
4. Thickener	300 gpm	84,000
5. Drying Beds	3 acres Loader	91,000
6. Oxidation Ponds	4 acres	56,000
7. Dryer		100,000
8. Compressor		180,000
9. Engineering (approximately 5%)		120,000
10. Contingency (approximately 10%)		217,000
		\$2,507,000



Compared to the cost of drilling a well which has one chance in forty-two of being a producer of any commercial quantity, this "wildcat" in ERA's opinion will result in the eventual production of upwards of 60 million cubic feet per day indefinitely, just from feedlots in the High Plains area.

TABLE II

COST FACTORS FOR HEREFORD HYMETH PLANT

Capital Costs

<u>Item</u>	
Digesters, Heated, Mixed	\$1,456,000
Appurtenances	714,000
Engineering, Contingency	337,000
Total	\$2,507,000

Annual Operation and Maintenance Costs

Manure at \$1.50 ton (Wet)	483,000
Labor at an average daily wage of \$40	162,000
Electrical @ 2.0¢/KWH	58,000
Water @ 6¢/1000 gallons	5,000
Lime, Polymers	37,000
Maintenance and Overhead	224,000

Subtotal	\$969,000
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Amortization @ 1% per month	300,000
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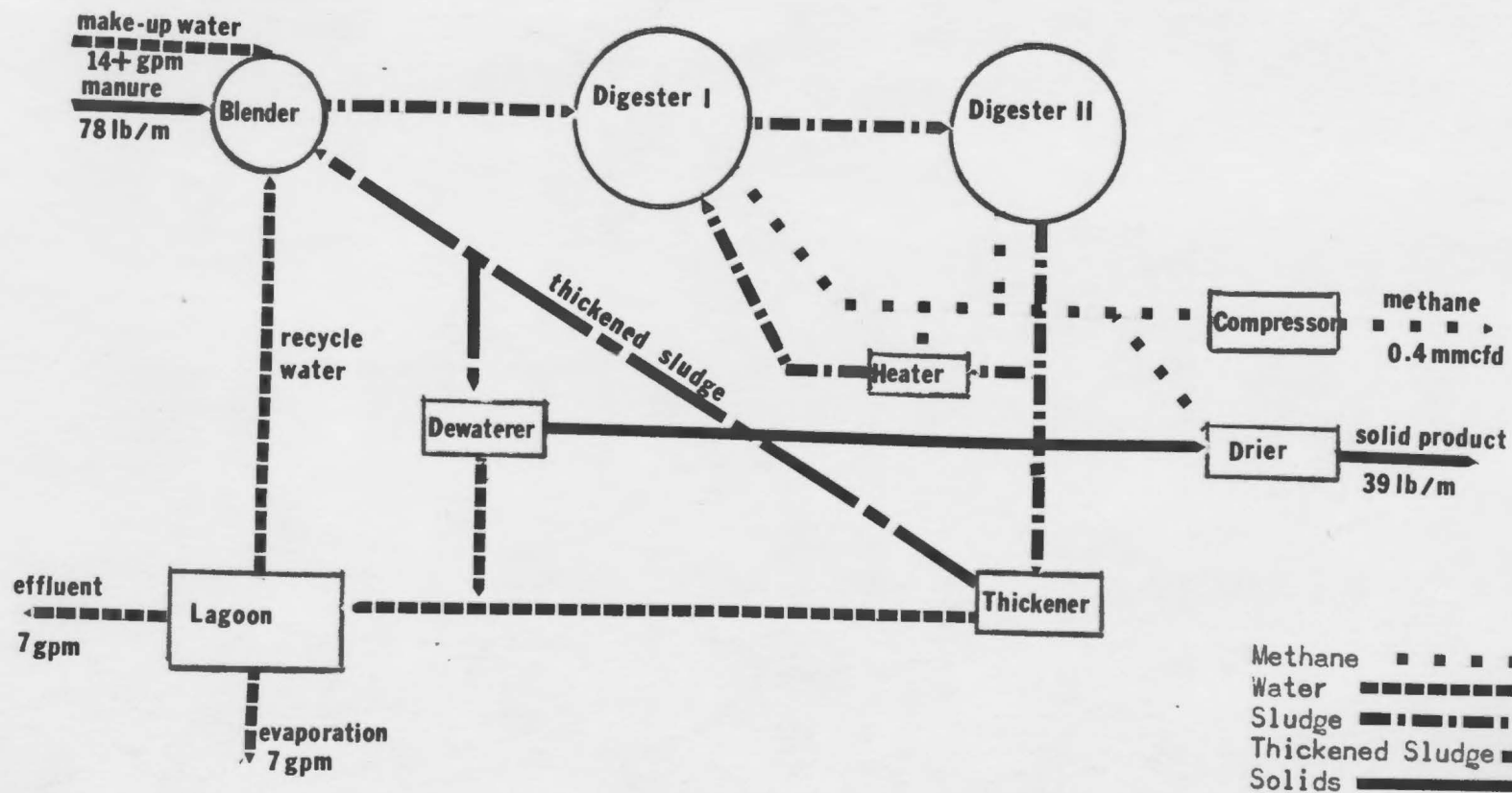
Total Annual Cost	\$1,269,000
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Approximate Cost per Million BTU's

- (1) Total Cost \$1.24
- (2) With \$10/ton Sludge Credit \$0.58
- (3) With \$20/ton Sludge Credit \$0.00



Figure 2
0.4 Million CFD
Hymeth Module



V Summary of Data Collection and Evaluational Studies

The research will involve a significant amount of analytical work. TOC, bacterial counts, volatile acids, alkalinity, pH, sodium, ammonia, total solids and total volatile solids will be required for digestion control studies. Methane, carbon dioxide and hydrogen sulfide measurements will be made for volume and quality of gas production. Organic nitrogen, phosphorous, potassium and volatile solids will be monitored on the digested sludge for potential soil conditioning and feed values. Various solids and liquids retention times will be evaluated for relative efficiency. It will be important to establish the tolerance levels of inhibiting ions and to determine the practical population dynamics of such a system before scale-up.

Another item for evaluation is the efficacy of certain commercially available inoculum. One product in particular, marketed by Gerald Bowers of Orange, California, claims gas production of more than 18 cubic feet of gas per pound of volatile solids added.³² While we believe that such values may be possible (by a strain of bacteria capable of dealing more effectively with the volatile solids that normally are resistant to digestion),²⁹ we would prefer to reserve judgment until some first hand observations are made. The Chicago operations have recorded values as high as 23 cubic feet of gas per pound of volatile solids destroyed.³³ With digestion efficiencies of 80 to 90 percent these gas production figures could be a reality.

The primary benefit of this evaluation study will be to provide an abundance of empirical information for other plants.

Operating sequences may be followed on Figure 6 of page 20.

(1) Manure is fed into the blender and mixed with water and thickened



seed to the proper consistency. (2) Diluted, seeded manure is continuously fed into Stage 1 digester which is continuously mixed and pressurized through standpipe common to Stage 1 and Stage 2. (3) From Stage 1 sludge flows into Stage 2 which is also continuously mixed. Sludge is also continuously recirculated from Stage 2 through an external heater into Stage 1. (4) Sludge is continuously withdrawn from Stage 2 and thickened. Approximately one-half of the thickened sludge is recirculated as seed into the blender; the remainder is applied to drying beds prior to final drying and sale. (5) Methane gas is withdrawn from the digester domes and compressed. For obvious reasons proprietary features are not shown in the figure.



Figure 3
Hymeth Profile

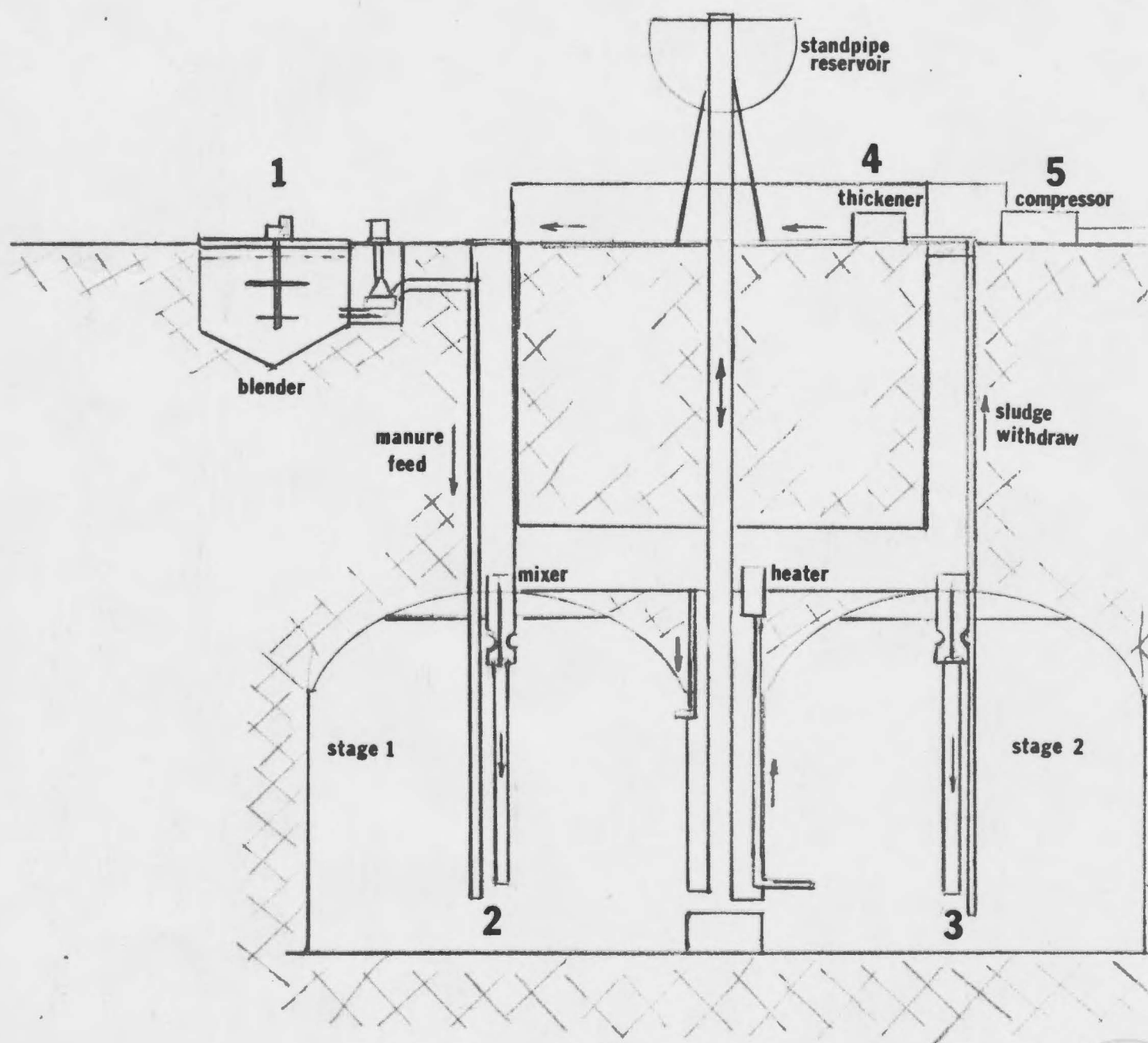


Figure 4 FEED LOT LOCATIONS



Packing Plant
Locations



Feed Lot Locations
5,000 Capacity
and Over

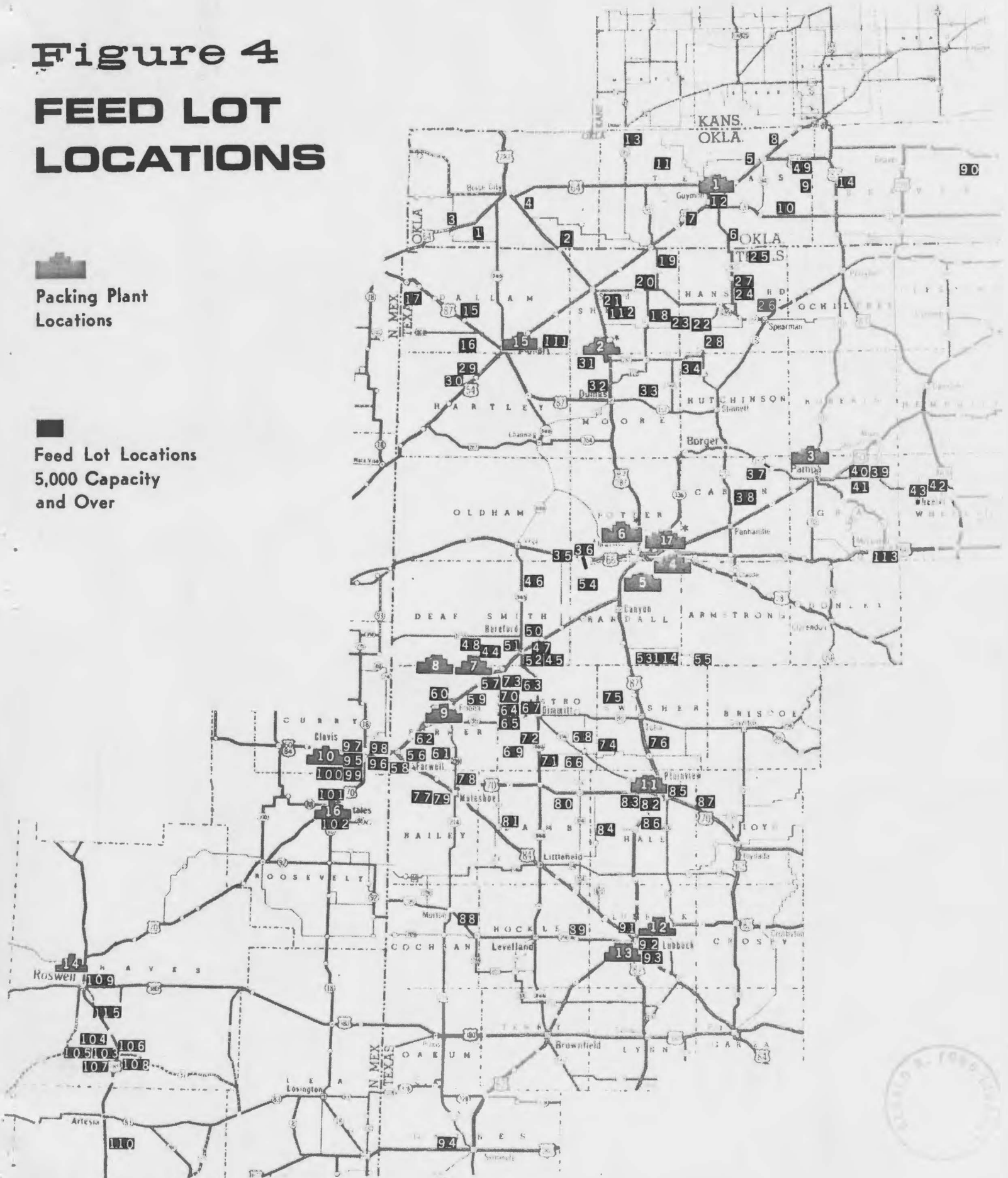


TABLE 111

CATTLE FEEDLOTS

COUNTY	NAME	SIZE	SITE NO.	COUNTY	NAME	SIZE	SITE NO.
Cimarron, OK	Boise City Feed Yard	8,000	1	Armstrong, TX	Parker Cattle Company	5,000	55
	Cimarron Feeders, LTD	24,000	2	Parmer, TX	Bovina Feeders, Inc.	30,000	56
	Felt Feeders	10,000	3		Cattletown, Inc.	35,000	57
	SGI Feedlot	11,000	4		Far-Tex Feedlot	15,000	58
Texas, OK	Grounds Feed Yard	6,000	5		Friona Feed Yard, Inc.	31,000	59
	Hitch, H. C. Feedlot	20,000	6		Hi-Plains Feed Yard	100,000	60
	Jones Feed Yard	5,000	7		Paco Feed Yard	37,500	61
	Master Feeders	74,000	8		Parmer County Cattle Co.	37,000	62
	McKinney Feed Yard	10,000	9	Castro, TX	Cimarron Feed Yard	12,000	63
	McKinney Feed Yard #2	5,000	49		Cluck Cattle Company	17,500	64
	Pride Feeders	24,000	10		Dimmitt Feedlot	45,000	65
	Sooner Beef	25,000	11		Hart Feeders, Inc.	10,000	66
	Texas County Feed Yard	22,000	12		Hill, Bud	7,500	67
	Glen Trim Feed Yard	5,000	13		Hill Feedlot	22,000	68
Beaver, OK	McGuire Feed Yard	5,000	90		Kemp & Kemp Feedlot	10,000	69
	Panhandle Feed Yard	14,000	14		Pre-Feeders, Inc.	22,500	70
Dallam, TX	Bar L Feedlot	9,000	15		Sunnyside Cattle Company	12,000	71
	Coronado Feeders	40,000	111		Taylor Feedlot	10,000	72
	Nortex Feedlot	16,000	16		United Beef Producers, Inc.	45,000	73
	Texline Feed Yard	6,000	17	Swisher, TX	Prairie Cattle Company	30,000	74
Sherman, TX	Cluck, Dean	11,000	18		Swisher County Cattle Co.	60,000	75
	Freeman Feedlot, Inc.	7,000	19		Tulia Feedlot, Inc.	28,000	76
	Walter Lasley & Sons	14,000	20	Bailey, TX	Bailey County Feeders	6,200	77
	Stratford Cattle Company	16,000	112		Chow-Tex Feedlot, Inc.	15,000	78
	Stratford Feed Yard, Inc.	60,000	21		King Feedlot	17,000	79
Hansford, TX	American Cattle Company	34,000	24	Lamb, TX	Olton Feed Yard, Inc.	28,000	80
	Caprock Feed Yard	30,000	22		Sudan Livestock & Feeding	25,000	81
	DGC Feeders	10,000	23	Hale, TX	Carter-Kirchoff	20,000	82
	Frontier Feeders	30,000	25		HCK Cattle Company	7,500	83
	Hansford Feed Yard	34,000	26		PGC-South Plains Division	35,000	84
	Harvey, T.C.	6,000	27		J. C. Rhoderick & Sons	10,000	85
	Palo Duro Feeders	18,500	28		Shepard Feedlot	12,000	86
Hartley, TX	Dalhart Feed Yard, Inc.	50,000	29	Floyd, TX	Lockney Feed Yard	30,000	87
	XIT Feed Yard	30,000	30	Cochran, TX	Owens Feed Yard	40,000	88
Moore, TX	Cactus Feeders, Inc.	40,000	31	Hockley, TX	Anderson-Skaggs	10,000	89
	Dumas Cattle Feeders	25,000	32	Lubbock, TX	Caprock Cattle Company	5,000	91
	Texas Beef Producers	36,000	33		Lubbock Feedlot, Inc.	45,000	92
Hutchinson, TX	McCloy, Wilson	10,000	34		Three "C" Cattle Co.	11,000	93
Oldham, TX	Mesa Verde Feed Yard	32,000	35	Gaines, TX	Gaines County Feeders	10,000	94
Potter, TX	PGC-West Plains Division	16,000	36	Curry, NM	Bogle & Bogle, Inc.	6,000	95
Carson, TX	Bond Cattle Company	6,000	37		Castor Feed Pens	20,000	96
	Carson County Feeders, Inc.	15,000	38		Clovis Feedlot	10,000	97
Gray, TX	Cockrell Cattle Company	20,000	39		Texico Feedlot	7,000	98
	Heaton Cattle, Inc.	22,000	40		Waldhauser, Ted	5,000	99
	McLean Cattle Company	25,000	113		Worley Feed Pens	25,000	100
	Moody Farms	18,000	41	Roosevelt, NM	Anderson-Skaggs	12,000	101
Wheeler, TX	Beef Cattle Company	25,000	42		Better Beef, Inc.	13,000	102
	Prime Feeders, Inc.	15,000	43	Chaves, NM	Barnett Feed Yard	27,000	103
Deaf Smith, TX	Big-Tex Cattle & Grain	37,000	44		Bogle Farms, Inc.	11,000	104
	Champion Feeders, Inc.	35,000	45		Chaves County Cattle Corp.	15,000	105
	Deaf Smith Feed Yard	35,000	46		Harshey Feedlot	5,000	106
	Hereford Feed Yard	50,000	47		Langenegger, Bill W.	15,000	107
	Pitman Feed Yards	60,000	48		Lankford, Royce	6,000	108
	Southwest Feed Yard	42,000	50		Pecos Valley Feed Yard	37,000	115
	Sugarland Feed Yard	25,000	51		Watson, Albert	6,000	109
	Texun Feed Yard, Inc.	15,000	52	Eddy, NM	Seven Rivers Cattle Company	25,000	110
Randall, TX	Happy Feedlot	20,000	114				
	Randall County Feed Yard	80,000	54				
	Seven Bar Feeders, Inc.	25,000	53				



TABLE IV
Production Factors
For a High Plains Methane Project

<u>Manure Values Dry Basis</u>	<u>Gross</u>	<u>Net</u>
Per Head per Day (Pounds) Dry Weight	9.2	--
Volatile Solids (Percent)	80	--
Methane per Pound Volatile Solids (Cu. ft.)	6.00	5.35
Methane per Ton Dry Manure (Cu. ft.)	9600	8560
Methane per Head per Day (Cu. ft.)	44.1	39.3
Service Base for One Million CFD (Hd)	22,700	25,400
Daily Tonnage (dry) for One Million CFD	104	117

Internal fuel expense for heating of digesters and new sludge is projected at 12%. The per head figure is based upon EPA estimates as is the volatile solids content. Methane production is conservatively based upon data from Loehr.²⁷

Projected Gas Composition

Methane - 98% Minimum

Carbon Dioxide - 2% Maximum



VI. Potential of the System

Table II, found on page sixteen gives preliminary cost analysis of a 2.8 million cubic foot per day methane plant in the High Plains area. These figures indicate that methane from a single 2.8 million cubic foot module would cost approximately \$0.58 per 1000 cubic feet, if sludge value were only \$10 per ton. These preliminary costs appear to be highly attractive compared to other sources of SNG³³ at upwards of \$1.00 and recent natural gas contracts for \$0.90 at wellhead.

Nationally the production of manure is over 2,000,000,000 tons annually.¹⁹ If the dry solids content of this manure is estimated at 20% and a net production of 8560 cubic feet of methane per ton is assumed (see Table IV), the total annual methane production from this source could amount to over 3.4 trillion cubic feet. This quantity plus a potential of 1.7 trillion from municipal solid wastes is equal to approximately one-fourth of the present annual natural gas consumption.³⁴

In addition to the gas, the sludge is taking on increased potential value as the energy crisis deepens. A shortage of energy is producing a shortage in manufactured fertilizer (primarily ammonia) and manufactured protein (primarily urea). By converting the noxious manure to an inoffensive humus material with much value as a soil conditioner with at least limited fertilizer value and possible feed value, the system could become quite lucrative. Value of the sludge as a soil conditioner is upwards of \$25 per ton bulk, FOB plant site.

Based upon a \$25 per ton sludge value, \$1.00 per Thousand cubic feet methane value and cost factors of Table II, the after-tax return on investment for a 2.8 million cubic feet per day plant would approximate 31 percent.

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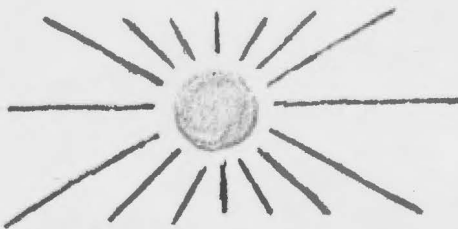
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A TECHNICAL SURVEY
OF THE
WRAP SYSTEM



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THE WRAP SYSTEM

Water and Nutrient Conservation Through an Algal-Chemical System

Abstract

An algal-chemical wastewater treatment process is described, which produces an effluent superior to activated sludge treatment. A pilot plant has consistently produced an average BOD₅ of less than 2.0 mg/l, total phosphates of 0.1 mg/l, total coliforms of 0.0 per 100 ml, accompanied by high COD and total nitrogen reductions and significant reductions in hardness and silica. Costs projected for scale-up indicate the process is competitive with activated sludge except where available land values exceed some \$15,000 per acre. Special features of the system include a multiple pond process which allows high loading rates, biological pH adjustment, oxygen backloading, magnesium coagulant recycle, dissolved air flotation and caustic disinfection.

The process is viewed as an economical answer to the problem of meeting increasingly stringent effluent standards. The reclaimed water is potentially useful as a cooling water without further treatment. The recovered by-products have potential value in livestock feeds as well as certain areas of the chemical industry.



Background

In recent years there has been a concerted effort to develop an economical means of treating wastewater to a quality beyond that achieved by conventional secondary treatment, (i. e., trickling filters and activated sludge). At South Lake Tahoe, California, a plant has been in operation for several years which is highly effective in producing an advanced degree of treatment. The plant achieves greatly reduced levels of organic waste matter, phosphates, fixed nitrogen, bacteria, and suspended solids. The Tahoe plant consists of a conventional activated sludge plant followed by lime precipitation for phosphate removal, an ammonia stripping tower for fixed nitrogen removal, mixed media filtration for suspended solids reduction, carbon absorption for polishing and removal of dissolved organic material and chlorination for control of bacteria and virus. These added steps make the process rather expensive in comparison to secondary treatment.



Summary of the process

The WRAP (Water Reclamation - Algae Production) process features several innovations as Figure 1 indicates. In its simplest configuration, raw sewage flows into the first of a series of three ponds. This first pond has an initial section which is considerably deeper than the remainder of the pond where sludge accumulates. This deep section is at least ten feet in depth and may be in excess of twenty feet. The remainder of this pond is operated at a nominal depth of six feet. The overall loading rate on this pond area should range between 2 and 10 pounds of BOD per 1000 cubic feet. In it organic waste materials are degraded into simpler organic intermediates and inorganic materials. This pond is largely anaerobic except for a zone near the surface. A considerable amount of photosynthetic activity occurs at the surface of this pond in warmer weather. This first pond is primarily effective through bacterial action and is called the facultative pond. This area may be loaded at 10 to 20 pounds per 1,000 cubic feet in summer, but to allow for winter conditions a more conservative two pounds is used. (at 34° latitude - 3,000 feet elevation).

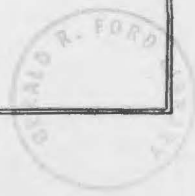
The second pond is primarily effective through the activity of algae and is called the aerobic pond. This pond is approximately one foot in depth and is mixed periodically. It is designed to produce a relatively high-density culture of algae. Effluent from the initial pond flows into it and the algae culture rapidly starts to assimilate the inorganic and intermediate organic materials. The shallow depth allows adequate exposure to sunlight even when the culture has a high density of algae. Mixing provides improved availability of nutrients to the algae, helps keep pH values low, discourages the growth of

predators such as daphnia, and prevents the growth of pests, such as midges. Detention in this pond is approximately 48 hours.

The third pond is called a decarbonation pond. It is operated at six inches or less in depth and detention is less than 8 hours. It is not mixed and is normally drained at the termination of each day's operation. The function of this pond is to produce a high pH value in order to reduce the lime dosage required in the flotation step. The uptake of carbon dioxide from the bicarbonate dissolved in the water produces this upward shift in pH. This pond also attains supersaturation levels of oxygen; this facilitates flotation.

During afternoon hours (normally from 12:00 noon to 9:00 or 10:00 p. m.) culture is continuously withdrawn from the final pond. Adequate lime or other alkaline material is added to raise the pH to approximately 11.4 so that magnesium coagulates and the voluminous gel picks up suspended solids (primarily algae) from the water. A portion (up to 30 percent) of the flow from the decarbonation pond has air dissolved in it in a pressurized tank. This portion of the flow is released under pressure (30 - 60 psi) and mixed with the incoming alkalized culture. The micro bubbles which form, buoy this magnesium hydroxide-algae gel to the surface of the flotation tank. Skimmer blades continuously remove this froth blanket.

Underflow water goes to a stripping basin where it is retained for approximately 12 hours to effect sterilization and sprayed into the air to allow ammonia to escape. The water is then recarbonated to pH 9.0 to 9.5 for stabilization. Finely divided calcium carbonate precipitates and is separated by sedimentation. This results in a sparkling clear, soft, stable, sterile water which should average approximately 1.0 mg/l BOD, 0.1 mg/l total phosphate and show a nitrogen reduction averaging over 80 percent.



The froth skimmed from the flotation unit is then reacted with carbondioxide to neutralize the magnesium Hydroxide. Following gravity thickening, calcium carbonate is centrifugally classified from the algae. The algae is dewatered either by centrifuge, filter, or dewatering beds and dehydrated to a final product. The magnesium-rich solution which is separated during thickening and dewatering may be recycled to maintain an optimum magnesium coagulant level and improve buffering of the culture or it may be routed to an evaporation pond where magnesium carbonate may be recovered as a by-product.

Another option for the flotation froth is to store it for twelve or more hours, allowing the alkaline condition to hydrolyze the protein from the algae. Calcium carbonate is then centrifugally classified; the decant water is acidified to pH 4.5; this dissolves magnesium hydroxide and precipitates protein. The protein is dewatered by filter or centrifuge and then dried; the magnesium-rich water then is recycled or evaporated for magnesium recovery.

Pilot Plant Feeding and Pond Experience

During the first year of operation of the pilot plant, primary clarified waste was used exclusively and the plant was operated quite consistently with little trouble. In the Spring of 1971 the plant pick-up point was moved from the outlet of the City's primary clarifier to the raw sewage distribution box. At this point, of course, much larger quantities of sludge were picked up.

Operating characteristics of the plant changed considerably within about two weeks following this change. Coagulation of the suspended algae began to require larger chemical dosages and decarbonation pond pH levels were lower than normal. The change was brought about by

an imbalance in the fermentation of the increased sludge loading. The prevalence of acid fermentation over methane fermentation resulted in organic acids carrying over into the decarbonation pond. These acids tended to chelate the coagulants and made larger chemical dosages necessary.

A rather simple remedy was found to be effective in reversing this condition. Sludge entering the facultative pond was fairly well-distributed over the bottom of the pond. This meant that conditions for methane fermentation were rarely ideal because of intermittent exposure of the sludge to molecular oxygen and the release of organic acids without benefit of methane fermentation. Methane bacteria are generally considered obligate anaerobes and therefore unable to live in the presence of molecular oxygen. To rectify the situation the inlet end of the facultative pond was deepened to approximately ten feet in depth and a dike which was within about six inches of the water surface was used to separate the deep initial section from the remainder of the facultative pond. This resulted in the accumulation of essentially all of the sludge in the deepened end of the pond. Operating characteristics of the ponds gradually improved as fermentation became balanced in the deep area and fermentation of the older sludge went to completion. By localizing sludge accumulation the organic acids had more exposure to the strictly anaerobic conditions necessary for methane fermentation. This was also beneficial to algae growth because the carbon dioxide produced in conjunction with the methane was available for increased algae production.

During more than three years of operating experience on the pilot plant a number of proprietary innovations have been developed which cannot presently be revealed either because they are patent pending or they are considered in-house technology which will remain in-house and

unpatented. These developments have added greatly to the reliability of this process and to the consistency with which the plant may be operated.

The Multiple Pond Concept Refined

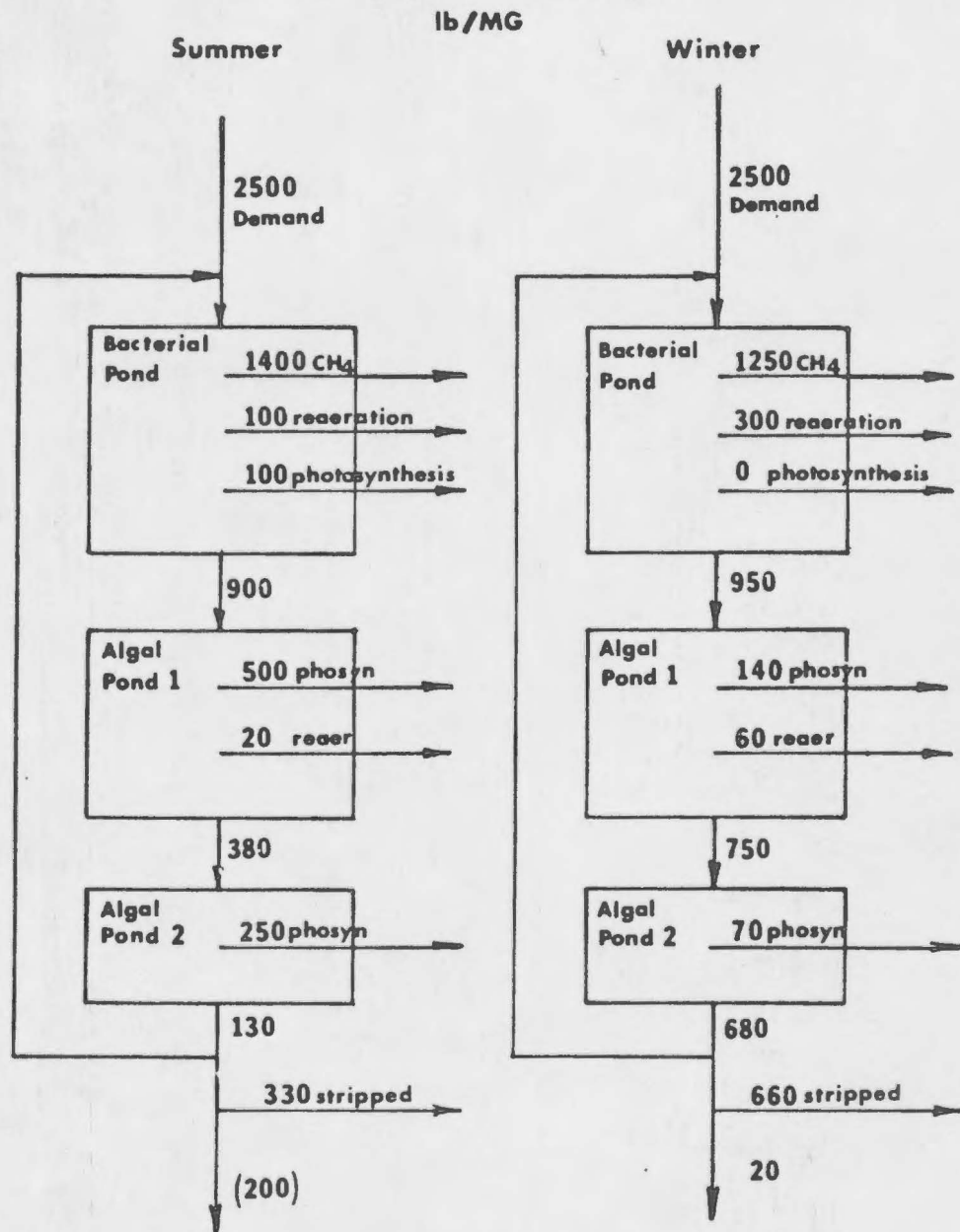
The multiple pond system allows much higher loading rates and reduced land requirements compared to simple ponding operations. This is primarily a result of increased oxygen resources and more efficient use of those resources in the multiple pond system. (Figure 2). According to Oswald a conventionally operated facultative oxidation pond has oxygen resources of approximately 52 to 70 pounds per acre per day. (1) Thirty to 33 pounds is represented in reduced oxygen demand resulting from methane fermentation. Seven to fourteen pounds is available from atmospheric reaeration and 15 to 23 pounds from photosynthetic activity. By comparison a pond loaded to anaerobic levels has an oxygen equivalent of some 330 pounds per acre per day from methane fermentation and 47 pounds from reaeration for a total of 377 pounds in total oxygen resources. On the other end of the scale, high-rate (shallow) ponds have upwards of 152 pounds per acre per day almost exclusively from photosynthetic activity.

An excellent example at Clovis, New Mexico, is an existing pond loaded with meat packing wastes having COD values of 5600 mg/l; effluent runs 610 mg/l. The high loading efficiency of such anaerobic ponds is offset by the production of odors which prohibit their use near populated areas. Used in combination with shallow ponds as oxygen generating basins for recirculation, very high loading rates can be employed without odor problems.

The shallow ponds can generate as high as 700 pounds of oxygen per acre per day. Each pound of algae cells generated is accompanied



2. Oxygen Budget



by the generation of about 1.6 pounds of oxygen. With a retention of over two days in the shallow ponds, algae density jumps from under 50 mg/l to as high as 800 or 900 mg/l under favorable weather conditions. For design purposes the more conservative figure of approximately 150 pounds of oxygen generation per acre is appropriate. By recirculation of a small portion of the oxygen-rich, alkaline, shallow-pond culture a film of oxygen and alkalinity can be maintained on the surface of the highly loaded initial pond. This film is adequate to control odors from the pond. The odor control capability is largely the result of the alkaline nature of the film. Odors from anaerobic lagoons are primarily from the acid fermentation reaction which produces organic acids. The odors indicate an imbalance between acid-forming and methane bacteria. Volatile acidic compounds can escape to atmosphere only when pond surface conditions are acidic.

The high absorption capacity of the shallow ponds for solar energy keeps pond temperatures high during the day. In addition, the oxygen generation produces values of three to four times saturation in the shallow culture. These two factors usually make the recirculation water less dense than the water of the first pond and facilitate the formation of a surface film during daylight hours. In cold weather the shallow algal pond culture may be cooler than the deep bacterial pond and direct recirculation of the denser material would disturb the methane fermentation process.

For this reason recirculation water should be pre-mixed with warm influent in cold weather. Even without recirculation the deep ponds need not generate objectionable odors in cold weather, if proper design considerations are used. If the fresh sewage inlet to the deep ponds is near the surface of the ponds and the inlet is designed for low

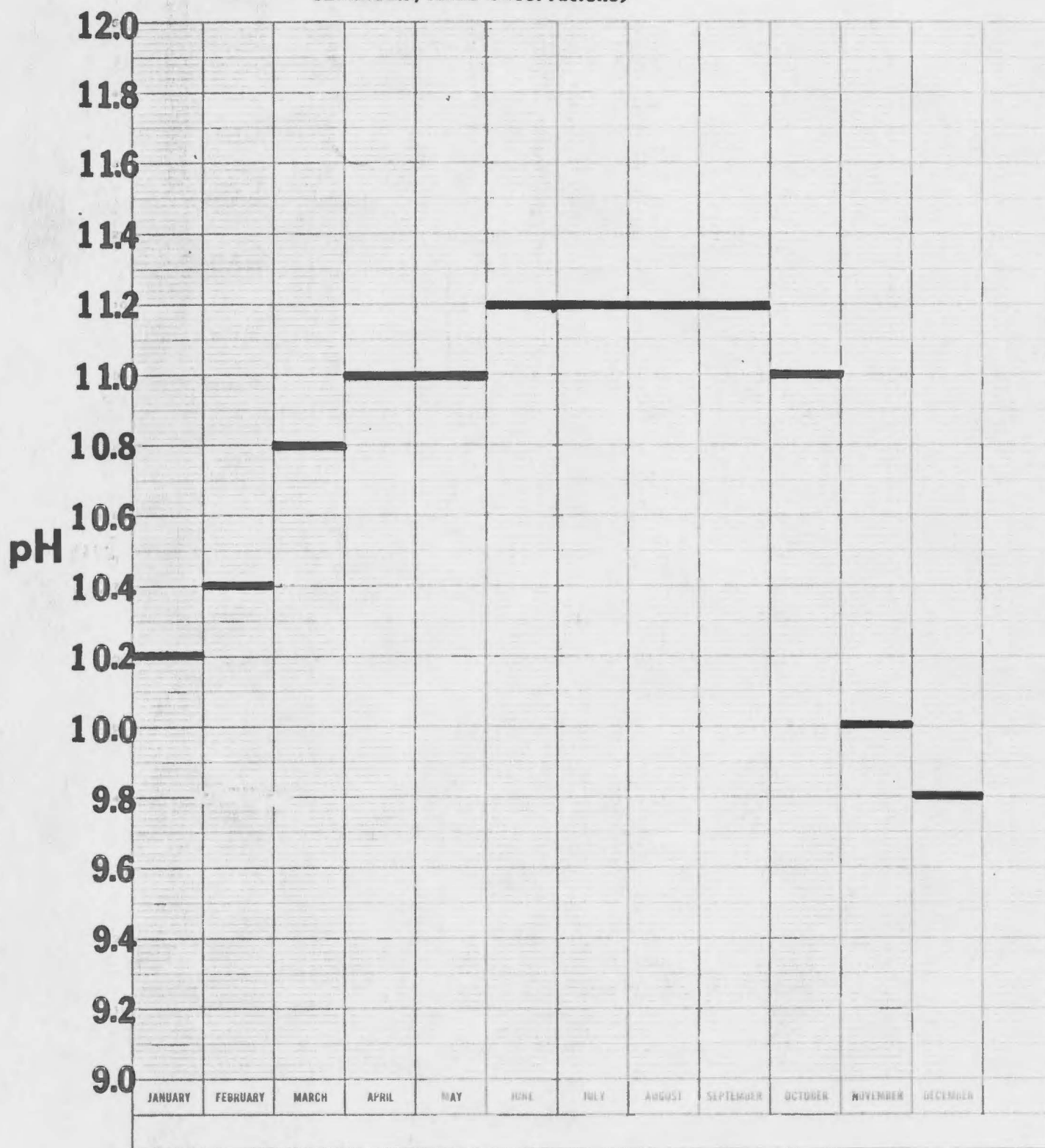
turbulence, so that mixing is not encouraged, the warm fresh sewage will form a surface layer on the pond. This layer will be nearly neutral in pH and will keep odors from escaping into the atmosphere.

Another design feature which can be quite beneficial is the placement of the bacterial pond outflow at the proper depth. A depth of between approximately 12 and 24 inches below the surface of the deep initial pond is advisable. At this depth only a small portion of any photosynthetic growth is transferred to the aerobic ponds. This encourages a build-up of algal activity on the surface and reduces the need for recirculation water.

The decarbonation pond is operated at about 6 inches of depth, compared to six feet in the first pond and approximately 12 inches in the middle pond. The primary function of this pond is to allow algal activity to elevate the pH of the water and in so doing reduce the lime requirements during phase separation. By the time culture reaches the decarbonation pond, much carbon from organic sources has been depleted and in addition, bacterial activity is much reduced because of environmental factors in the very shallow pond. In the decarbonation pond the primary source of carbon for algal growth is the bicarbonate in the water. Each CO_2 assimilated from bicarbonate leaves one hydroxyl ion. This produces a rise in pH and in the Lubbock area it is possible to achieve pH values in the area of 11 from March through October. In winter pH values normally run between pH 9.0 and 10.0. (See Figure 3). Such pH values result in a reduction in lime dosage which for many waters would amount to a savings of 60 to 80 percent. Under laboratory conditions pH values in excess of 12 have been produced by this phenomenon. (2) In the Lubbock pilot plant pH levels of 11.2 are not uncommon in favorable weather. The high pH values are accompanied by super-saturation of

3. Maximum Decarbonation Pond pH

(Lubbock, Texas Observations)



the water with oxygen and a rise in temperature. If wind action is present, autoflocculation and flotation of algae will occur in this pond area. In a properly designed system a number of incidental benefits can be derived from the decarbonation pond. With proper capacity the pond can produce a culture which is nitrogen limiting and can produce high levels of nitrogen reduction.⁽³⁾ The high pH coupled with the wind action can also lose significant amounts of ammonia nitrogen to atmosphere; also, it produces precipitation of calcium phosphate and under certain conditions ammonium calcium phosphate.⁽¹⁾ In addition, significant reduction in coliforms results from exposure to ultraviolet light, extracellular algal products and high pH. The high concentrations of algae cells and the associated oxygen generation assure a final water which is high in dissolved oxygen. Also, the quiescence of the pond allows older, poorer-quality algae cells to settle.

During operations in 1970, precipitation trials were run using supplemental phosphate in the decarbonation pond. The intent of the trials was to ascertain the feasibility of attaining high levels of ammonia removal by precipitation of ammonium calcium phosphate, one of the few compounds of ammonia which is relatively insoluble. The gist of this experience indicates that while there is considerable merit in an approach which could remove both nitrogen and phosphorous in one chemical reaction, control is rather difficult and additional refinement is required.

Dissolved Air Flotation

The initial design on the pilot plant included a tube-settler equipped sedimentation tank. During operation it was found that the tube settlers worked very well during the morning but in the afternoon

problems developed. The actively photosynthesizing algae culture became supersaturated with oxygen in the afternoon. Then, in spite of anything that was done to prevent it, the algae would tend to float and would break through the tube settlers and rise to the surface of the sedimentation tank. Rather than fight this phenomenon it was quickly decided to cooperate with the natural tendency and convert to a flotation process. Various flotation configurations were tried and flotation was found to be a very effective technique for algae separation. The vertical type tank which was converted from sedimentation worked reliably but was considered less than optimum for scale-up purposes. A horizontal pilot unit was designed and operated. This unit was more efficient but also more critical for operation. The horizontal design is considered more practical for scale-up process.

Three pressurized air configurations were also tried. Direct full flow pressurization is very effective but involves high pumping costs and potential maintenance problems. Partial recycle of underflow water is also quite effective but has much lower pumping requirements and potentially less maintenance. Finally, partial or split flow pressurization was found to be the best combination of efficiency and economy.

Phase separation is basically a modified cold-lime process. Traditionally, cold-lime treatment has used sedimentation tanks for phase separation with detention times of up to two hours. Through the use of dissolved air flotation a detention time in the flotation tank of only 12 to 15 minutes is required.

Much of the time no supplemental dissolved air is required because of the high oxygen content of water coming from the final pond. Supersaturation oxygen forms micro bubbles after undergoing a pressure change as it passes through the feed pump. Supplemental air is supplied

by pressurizing up to 30 percent of the flotation tank effluent to about 50 psi and introducing the pressurized water into the flotation tank influent. The supplemental dissolved air allows the flotation unit to operate efficiently and produce a relatively high quality effluent regardless of weather conditions.

Because pH levels from the decarbonation pond are highest during the late morning hours through the hours shortly after sunset, the flotation unit is designed for operation during those hours only.

The most notable application of dissolved air flotation to cold-lime treatment is at Windhoek, Southwest Africa, where reclaimed sewage water is recycled to provide about 30 percent of the city's domestic water supply. (4)

Caustic Disinfection

After passing through the flotation tank the underflow water is held for approximately twelve hours before being recarbonated. Spraying of this high pH water into the air during this period allows ammonia to be stripped. The delay in recarbonation produces a water that is essentially sterile. The high pH inactivates virtually all bacterial and virus cells. (5)

The results achieved compare very favorably with the use of chlorination of wastewater effluents. Only occasionally in the literature does chlorination result in total coliform counts of zero and then not consistently for a given effluent.

Although ammonia levels in the water are normally low in warm weather (when spraying may be curtailed) the ammonia removal in this step may be quite significant in cold weather.



By-Product Processing

Froth which has been skimmed from the flotation unit consists primarily of algae cells and calcium carbonate enmeshed in magnesium hydroxide gel. This fresh froth ranges between 4 and 6 percent solids normally. In order to have a by-product with potential commercial value it is necessary to separate calcium carbonate and magnesium hydroxide from the algae cells.

The denser calcium carbonate is readily separated from the algae and magnesium by centrifugal classification. A solid bowl centrifuge does an excellent job of classification. At South Lake Tahoe centrifugal classification is used to separate phosphate and magnesium from calcium carbonate prior to recalcining; although the principal is similar the cost of centrifugal classification is relatively high.⁽⁶⁾

Prior to classifying the calcium carbonate it has been found to be beneficial to react the froth with carbon dioxide. This converts magnesium hydroxide to the soluble bicarbonate and facilitates classifying. Gravity thickening for about 12 hours after classifying has been found to be advisable. The thickened froth will average 8 to 12 percent solids. The algae are next dewatered with magnesium being carried in the solution. Dewatering may be by centrifuge, filtration or beds. In this way the bicarbonate can be recycled to provide buffering capacity in the pond system and magnesium can be maintained at an optimum level as the primary coagulant and also can be beneficial in odor control. After dewatering, the algae is ready for dehydration and storage.

In working with the froth it was found that if the materials were allowed to stand at a high pH for a number of hours before dewatering the algae cake came through with very low protein value. An analysis of the extracted water showed a high Kjehldahl nitrogen

level, indicating that hydrolysis of the protein has occurred. A check of the literature showed that Russian workers had done research in the area of mechanically breaking algae cells and extracting protein from algae with caustic solutions to produce a high quality concentrate. (7) Acidifying the hydrolyzed protein to pH 4.5 produces precipitation and a potentially valuable refined product.

Discussion of Process Performance

Table I lists the performance values recorded at the pilot facility during a continuous run of over four months in 1973.

PILOT PLANT PERFORMANCE

TABLE I

	<u>In</u>	<u>Out</u>	<u>Reduction</u>
BOD ₅	412 mg/l	1.8 mg/l	99.5%
Suspended Solids	343 mg/l	6.3 mg/l	98.2%
Total Phosphorous	16 mg/l	0.04 mg/l	99.6%
Ammonia Nitrogen	34 mg/l	1.3 mg/l	96.2%
Total Hardness	260 mg/l	85 mg/l	67%
Total Coliforms *	20,000,000/100 ml	zero/100 ml.	100%
Enterovirus *	1844/gal	zero/gal.	100%

*Not monitored during 1973 tests - Values from earlier trials.

Conventional processes such as activated sludge do not produce an effluent even roughly comparable (8, 9, 10, 11) to the WRAP System. A comparison with the results obtained at the South Lake Tahoe

plant (Figure 4) will show that the pilot plant operated at efficiencies approximately equal to those at Tahoe, which is generally considered the world's most advanced plant. (10, 11) BOD and coliform removal are essentially identical for Tahoe; phosphorous and nitrogen reduction is slightly better and suspended solids are slightly lower.

Pilot Plant Testing Programs

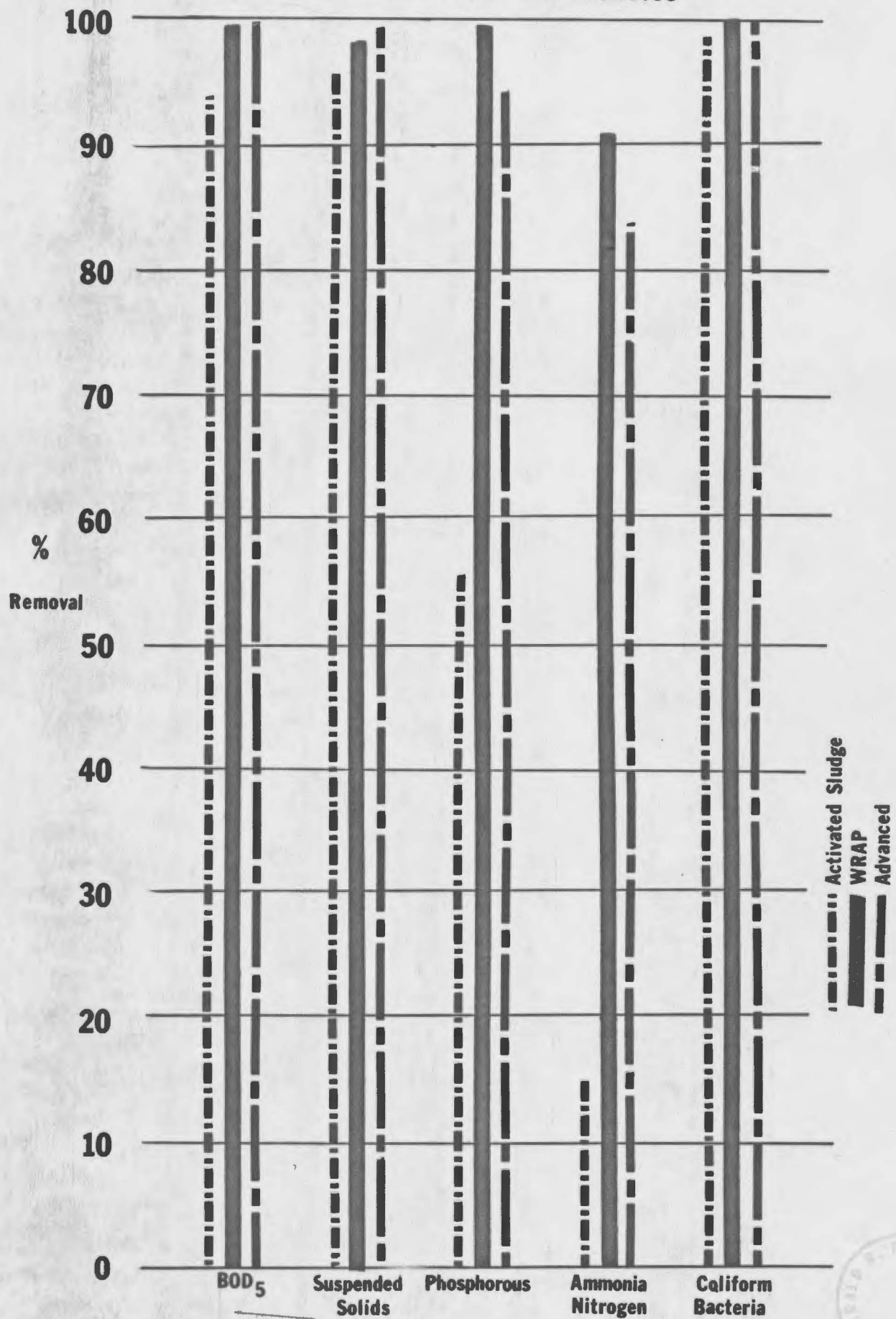
The WRAP pilot facility was initially placed in operation in April 1970. For approximately one year the plant was fed from primary effluent from the City of Lubbock's Number 2 Treatment Plant. The average of the several tests made during this period at normal design throughput are summarized below.

TABLE II
PHASE 1 TESTS

<u>Test Item</u>	<u>Feed*</u>	<u>Final Effluent*</u>	<u>% Reduction</u>
BOD ₅	290	1.0	99.6
COD	700	56	92.0
Suspended Solids	268	29	89.8
Organic Nitrogen	9.5	1.6	83.3
Ammonia Nitrogen	71.9	11.7	83.8
Nitrate Nitrogen	0.4	1.7	--
Orthophosphate-Phosphorous	11.6	0.05	99.5
Total Phosphorous	14.0	0.07	99.5
Silica	52	7.3	86.0
Total Coliform	1.6 X 10 ⁶ /100 ml	0	100
Enterovirus	1844/gal	0	100

*All units are mg/l unless otherwise designated.

4. Comparison of Process Efficiencies



During this period of operation only suspended solids, ammonia nitrogen and COD removals were considered unsatisfactory. Suspended solids levels were primarily the result of carryover of finely divided calcium carbonate from recarbonation. Ammonia nitrogen reflected inadequate shallow pond detention for the relatively high level of nitrogen being fed. COD appeared to be largely a question of proper detention in the deep initial pond and also extracellular products from the algae.

In May and June of 1971 feed pick-up to the pilot plant was shifted to the City of Lubbock's grit chamber at plant Number 2 and a second phase of testing was begun. Difficulty in feeding from the grit chamber resulted in another shift to just ahead of the primary clarifier to avoid large pieces of material in the sewage which tended to clog the 2 inch feed line. During two months of continuous processing the test results summarized below were recorded.

TABLE III
PHASE 2 TESTS

<u>Test Item</u>	<u>Feed*</u>	<u>Final Effluent</u>		<u>% Reduction</u>
		<u>Range*</u>	<u>Average*</u>	
BOD ₅	322	0 - 3.0	1.1	99.6
COD	872	20 - 64	43	95.0
Suspended Solids	280	7 - 50	16	94.3
Organic Nitrogen	31	3.5 - 7.8	5.8	81.1
Ammonia Nitrogen	42	0.7 - 18.5	12.8	69.5
Nitrate Nitrogen	--	1.7 - 8.5	3.5	--
Orthophosphate Phosphorous	--	0.003 - 0.030	0.016	--
Total Phosphorous	--	0.020 - 0.060	0.040	--
Total Coliform	--/100 ml	0	0 /100 ml	100%
Fecal Coliform	--/100 ml	0	0 /100 ml	100%

*All units are mg/l unless otherwise designated.

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Dissolved Oxygen	0 mg/l	7.5 - 19.2	12.1 mg/l	--
Total Dissolved Solids	1470 mg/l	1515 - 1849	1697 mg/l	(16)
Hardness	252 mg/l	28 - 132	72 mg/l	71.5

Comparing the table above with that of the first phase shows significant improvement in COD and suspended solids. The fact that greater ammonia removal requires more shallow pond detention was evident. Better clarification aided suspended solids removal. COD improvement was primarily due to the employment of recirculation.

The most recent phase of testing involved over 4 months of continuous operation in which changes in throughput were evaluated. Also industrial reuse potential was investigated in addition to BOD₅ and suspended solids removal. During this phase several evaluations of extended detention in the pilot plant were recorded. The table below indicates performance of the plant in terms of BOD₅ and suspended solids at the throughputs indicated.

TABLE IV
EXTENDED DETENTION

Date	Throughput Percentage of Normal Design Capacity	BOD ₅ (mg/l)		Suspended Solids (mg/l)	
		Feed	Final Effluent	Feed	Final Effluent
May 18.	60%	455	13	313	12
May 19	60%		23		15
May 20	60%		--		--
May 21	60%		14		11
May 22	60%		22		7
May 23	60%		14		3
July 13	45%	510	40		6
July 20	60%	480	15		12
		95.6% Reduction		97% Reduction	

As these figures indicate, effluent quality is rather poor under increased detention. Metabolism of organisms within the system becomes endogenous primarily and as a result process performance declines.

When the system was operated at design throughput or above, effluent quality was excellent in terms of BOD₅ and suspended solids as the following table indicates.

TABLE V
NORMAL DETENTION

<u>Date</u>	<u>Throughput As Percentage of Nominal Design Capacity</u>	<u>Normal Detention BOD₅ mg/l</u>		<u>Suspended Solids mg/l</u>	
		<u>Feed</u>	<u>Final Eff.</u>	<u>Feed</u>	<u>Final Eff.</u>
May 8	100%		7		4
May 9	100%	570	3	360	16
May 10	100%		0		11
May 11	100%		0		3
May 12	100%		0		2
May 13	100%		0		5
May 14	100%		9		12
May 15	100%		0		1
May 16	100%	610	0	282	1
May 17	60%		0		3
May 24	120%		0		2
May 25	120%	350	9	995	4
May 26	120%		5		3
May 27	120%		0		5
May 28	120%		0		12
May 29	120%		0		3
May 30	120%	720	0	189	9
May 31	120%		3		12
June 1	120%		4		5
June 2	100%		0		11
June 3	100%		0		7
June 4	100%		4		1
June 5	100%		6		3

June 6	100%	260	0	445	9
June 7	100%		0		8
June 8	100%		0		10
June 9	100%		6		3
June 10	100%		0		5
June 11	100%		0		13
June 12	100%		1		12
June 13	100%	180	1	296	2
June 14	100%		0		1
June 15	100%		4		6
June 16	100%		0		4
June 21	100%	390	5	475	7
June 28	100%	330	0	176	12
July 6	100%	270	0	200	7
July 27	100%	270	0	264	7
Average		411.7	1.8	343.4	6.3
% Reduction			99.5%		98.2%

In addition to BOD₅ and suspended solids the following ammonia nitrogen results were obtained on plant effluent during these phase three operations.

TABLE VI

Ammonia Nitrogen

<u>Date</u>	<u>Ammonia Nitrogen</u> <u>mg/l</u>
April 30	0.2
May 7	0.8
May 8	3.2
May 10	7.0
July 20	0.0
July 27	0.2
August 2	0.0
August 6	0.0
August 14	0.1

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August 21	0.3
August 28	4.0
Average	1.4

Based upon average influent ammonia nitrogen levels from city records the above reduction amounts to better than 95 percent.

During this phase additional tests were run to evaluate the potential of the process in reclaiming water for use in industrial cooling. Table VII below lists the results of tests which were run by the City of Lubbock wastewater laboratory.

TABLE VII
TOTAL DISSOLVED SOLIDS

<u>Date</u>	<u>Feed mg/l</u>	<u>Final Effluent mg/l</u>
August 14	1462	1278
August 15	1296	1294
August 16	1130	1307
August 17	1531	1597
August 18	1255	1397
August 19	1900	1191
August 20	1174	1294
August 21	1158	1090
August 22	1502	1292
August 23	1185	1397
August 24	1202	1497
August 25	1494	1276
August 27	1386	1414
August 28	1780	1796
Average	1390	1366



Five other sets of tests were run by a private laboratory (Plains Laboratory) during this same period with average values of 1493 mg/l TDS of feed and 1214 mg/l on final effluent. Hardness of the final water during this period averaged approximately 85 mg/l for an average reduction of 67 percent. Previous tests have recorded silica reductions of as much as 90 percent. High levels of silica reduction can probably be maintained quite readily by increasing magnesium recycle within the process. Phosphorous reductions averaging over 99.5 percent (from previous tests) are also a favorable factor in considering use of the water for cooling.

Projected Costs

Tables VIII through XII indicate the comparative costs of activated sludge treatment, extrapolated costs from South Lake Tahoe and projected WRAP System costs for a plant of 7.5 MGD capacity using EPA labor factors. Tahoe costs are taken from Evans. (12)

As Figures 5 and 6 also indicate capital and operating costs for WRAP plants are competitive with those of activated sludge and provide a treatment which is comparable to that produced at South Lake Tahoe. Projected costs for a 7.5 MGD plant run about 11¢ per 1,000 gallons compared to 43¢ at Tahoe.

Although the algal by-product normally has a protein content of 40-50% and is superior in biological value to soybean meal, market development is still a hurdle.

The reduced hardness and silica in the product water could be an economic factor because of its potential use as cooling water by industry in hard water areas.

TABLE VIII

WRAP PONDS SUBSYSTEM COST ANALYSIS - 7.5 MGD

<u>Capital Costs - Item</u>	<u>Facultative Ponds (Bacterial) 22.5 Acres</u>	<u>Aerobic Ponds (Algal I) 45 Acres</u>	<u>Decarbonation Pond (Algal II) 33.75 Acres</u>
Excavation and Backfill @ Typical	\$120,000	\$20,000	\$20,000
Bank Stabilization @ \$4.50/LF	22,000	24,000	16,000
Bottom Seal Only @ 3¢/sq. ft.	24,700	58,500	43,500
Bottom, Stabilize @ 5¢/sq. ft.	0	97,500	73,100
Baffles @ \$2.00/LF	8,000	32,600	4,800
Mixing Pumps (Installed)	0	76,000	0
Totals	\$174,700	\$306,100	\$157,400
Fence @ \$4.50/LF		56,000	
Grand Total		\$694,200	

Operating Costs - Item

Electricity	500 KWH/day @ 1.8¢	-	\$ 9.00 /Day
Operating Labor	@ \$5.67/hour	-	25.40 /Day
Maintenance Labor	@ \$4.99/hour	-	16.50 /Day
Repair Material		-	4.61 /Day
Instrument Maintenance		-	3.22 /Day
Total			\$59.66 /Day

	<u>1972 Dallas Regional Cost</u>	<u>1972 National Index</u>
Capital Cost per million gallons	\$17.79	\$20.13
Operating Cost per million gallons	7.95	9.26
	\$25.74	\$29.39

The above costs are based upon recent construction experience in the West Texas, Eastern New Mexico area; oxidation pond operating experience in the same area; and dealer estimates on sealant and stabilizer installation. The Summary of Costs reflects both the regional figures and national average from EPA at indices of 161.41 and 182.56 respectively.

Labor costs include all direct and indirect monies paid on employees behalf.

TABLE IX
WRAP FLOTATION SUBSYSTEM COST ANALYSIS - 7.5 MGD

CAPITAL COSTS - ITEM

Permutit Favair MK II Dissolved Air	
Flotation Units OBS-900 - 3 each	
(Installed and including lime feed, floculators and metal building)	\$594,000

OPERATING COST - ITEM

Electricity @ 1.8¢/KWH	\$28.35 /Day
Operating Labor @ \$5.67/hour	15.07 /Day
Maintenance Labor @ \$4.99/hour	8.50 /Day
Repair Material	3.05 /Day
Instrument Maintenance	1.93 /Day
Lime @ \$26.00/ton -(Maximum)	80.00 /Day
Total	\$136.90 /Day

Capital Cost	\$14.15 per million gallons
Operating Cost	\$18.25 per million gallons
	\$32.40 per million gallons

The above operating costs were derived from those experienced at South Lake Tahoe on a similar unit process; where appropriate adjustments have been made to reflect WRAP differences. For example flotation operation involves pressurized flow with somewhat higher pumping and electrical costs than Tahoe-type cold-lime clarifiers. Lime requirements are, however, much lower for WRAP. Other operating factors are very similar except that the flotation operation is based upon a 10 hour operating day. Capital costs are based upon 1972 vendor estimates corrected to 1973 EPA Index.

Labor costs include all direct and indirect monies paid on employees behalf.

TABLE X

WRAP ALGAE REFINING SUBSYSTEM COST ANALYSIS - 7.5 MGD

Capital Costs - Item

a. Thickener-Neutralizer - Installed	\$ 83,000
b. Classifier - Hydrocyclones	120,000
c. Dryer - Flash Dryer - Installed	112,000

Total	\$315,000
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Operating Costs - Items

	a.	b.	c.	Total
Electricity @ 1.8¢/KWH	\$5.08	\$1.08	\$2.70	\$8.86
Fuel @ 8.1¢/therm	24.00	.00	51.00	75.00
Operating Labor @ \$5.67/hour	8.16	10.03	30.05	48.24
Maintenance Labor @ \$4.99/hour	5.18	6.40	15.29	26.87
Repair Material	2.14	4.74	8.11	14.99
Instrument Maintenance	0.97	0.00	5.15	6.12
	\$45.53	\$22.25	\$112.30	\$180.08

Capital Cost - \$7.46 per million gallons

Operating Cost - \$24.01 per million gallons

Total	\$31.47 per million gallons
-------	-----------------------------

The above costs were taken directly from those experienced at South Lake Tahoe in dewatering (centrifugally) and recalcining lime-mud. Capital costs have been adjusted to 182.56 (EPA) National Index. At Tahoe lime-mud is first gravity thickened, as is the WRAP algae-lime froth. Next a solid bowl centrifuge dewateres lime-mud and classifies phosphorous at Tahoe; with WRAP, a centrifuge classifies and dewateres lime-mud from the algae. At Tahoe the phosphorous carry-over is then dewatered by a second centrifuge and the dewatered lime-mud is burned to regenerate lime and produce carbon dioxide. In WRAP, the algae is then dewatered by centrifuge and dried. Drying of the algae requires far less fuel than recalcining the lime-mud. Otherwise most operating costs should be comparable except that WRAP costs are for a 10 hour operating day and reflect lower operating labor and higher capital costs. WRAP does incorporate neutralization of the algae froth with carbon dioxide. This partially offsets the higher fuel cost entailed in recalcining at Tahoe.

Labor costs include all direct and indirect monies paid on employees behalf.

TABLE XI
WRAP WATER REFINING SUBSYSTEM COST ANALYSIS - 7.5 MGD

Capital Costs - Item

Recarbonator including clarifier basin and two stage carbon dioxide injection	\$241,000
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Operating Cost - Item

Electricity @ 1.8¢/KWH	\$12.74
Fuel @ 8.1¢/Therm	24.00
Operating Labor @ \$5.67/hour	16.32
Maintenance Labor @ \$4.99/hour	5.18
Repair Material	2.14
Instruments Maintenance	0.97
	\$60.35

Capital Cost	\$5.74 per million gallons
Operating Cost	\$8.05 per million gallons
	\$13.79 per million gallons

The above costs were taken directly from those experienced at South Lake Tahoe for recarbonation. Only the fuel cost for producing carbon dioxide varies from Tahoe costs. At Tahoe, exhaust gas from the recalcining operation supplies carbon dioxide. Capital Cost figures are adjusted to 182.56 (EPA) National Index.

Labor costs include all direct and indirect monies paid on employees behalf.

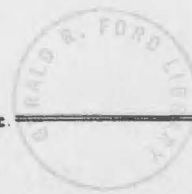


TABLE XII
WRAP SYSTEM COST ANALYSIS - 7.5 MGD

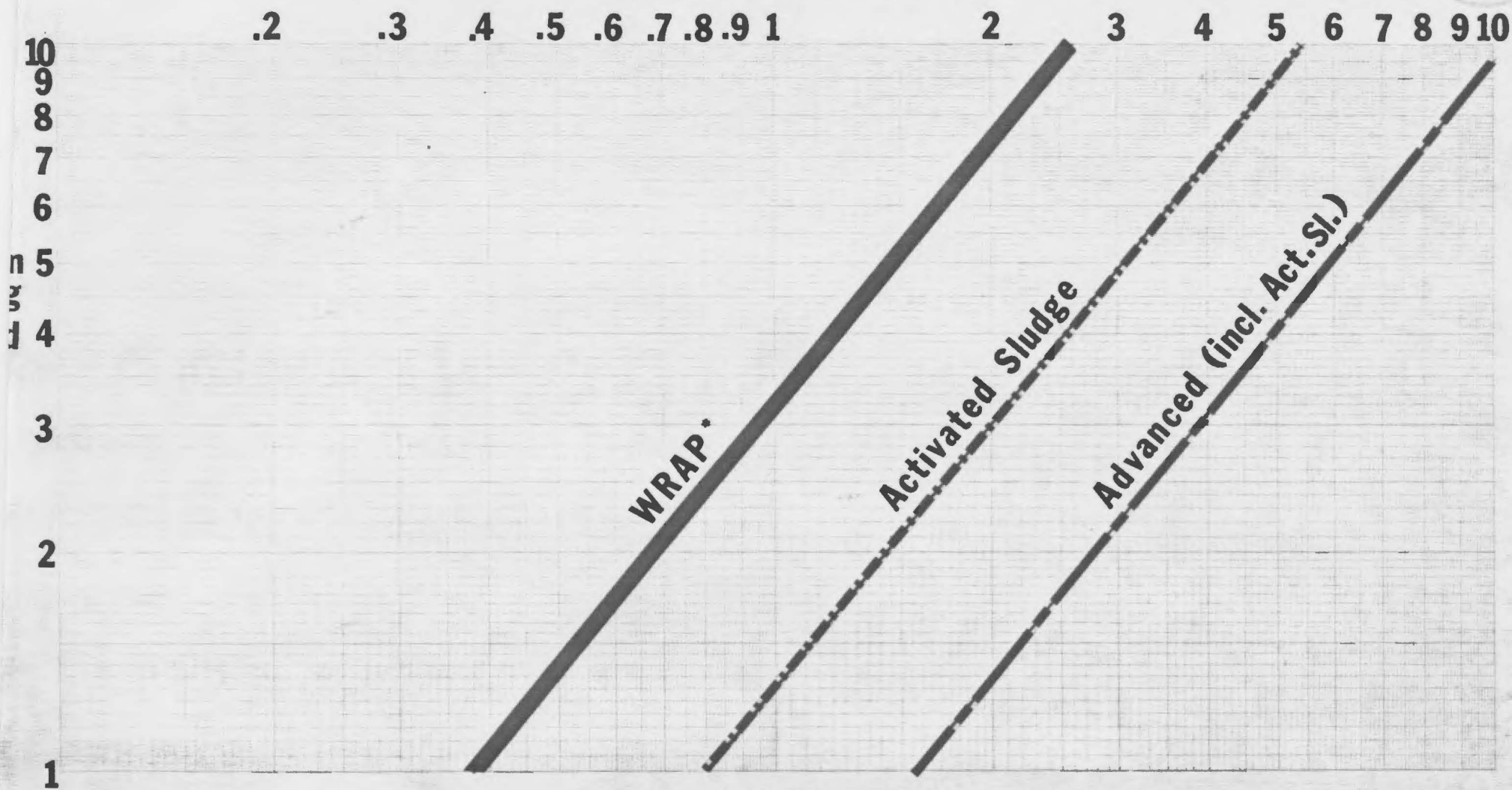
<u>PROCESS ITEM</u>	<u>OPERATING COST: \$ PER MILLION GALLONS</u>	<u>CAPITAL COST: \$ PER MILLION GALLONS*</u>	<u>TOTAL COST: \$ PER MILLION GALLONS</u>
Ponds Subsystem	\$ 9.26	\$20.13	\$29.39
Flotation Subsystem	18.25	14.15	32.40
Algae Refining Subsystem	24.01	7.46	31.47
Water Refining Subsystem	8.05	5.74	13.79
7.5 MGD WRAP System Cost Less Land	\$59.57	\$47.48	\$107.05
7.5 MGD South Lake Tahoe Activated Sludge Plant Only	\$104.51	\$96.75	\$201.26
7.5 MGD South Lake Tahoe Advanced Treatment Total Cost	\$242.10	\$203.56	\$445.66

*Based upon 25 years at 5% interest and adjusted to 182.56 (EPA) National Index; but does not include design costs.

WRAP plant Less Land	\$1,934,000
Activated Sludge Plant	\$3,941,000
Advanced Treatment Plant After Activated Sludge	\$8,293,000

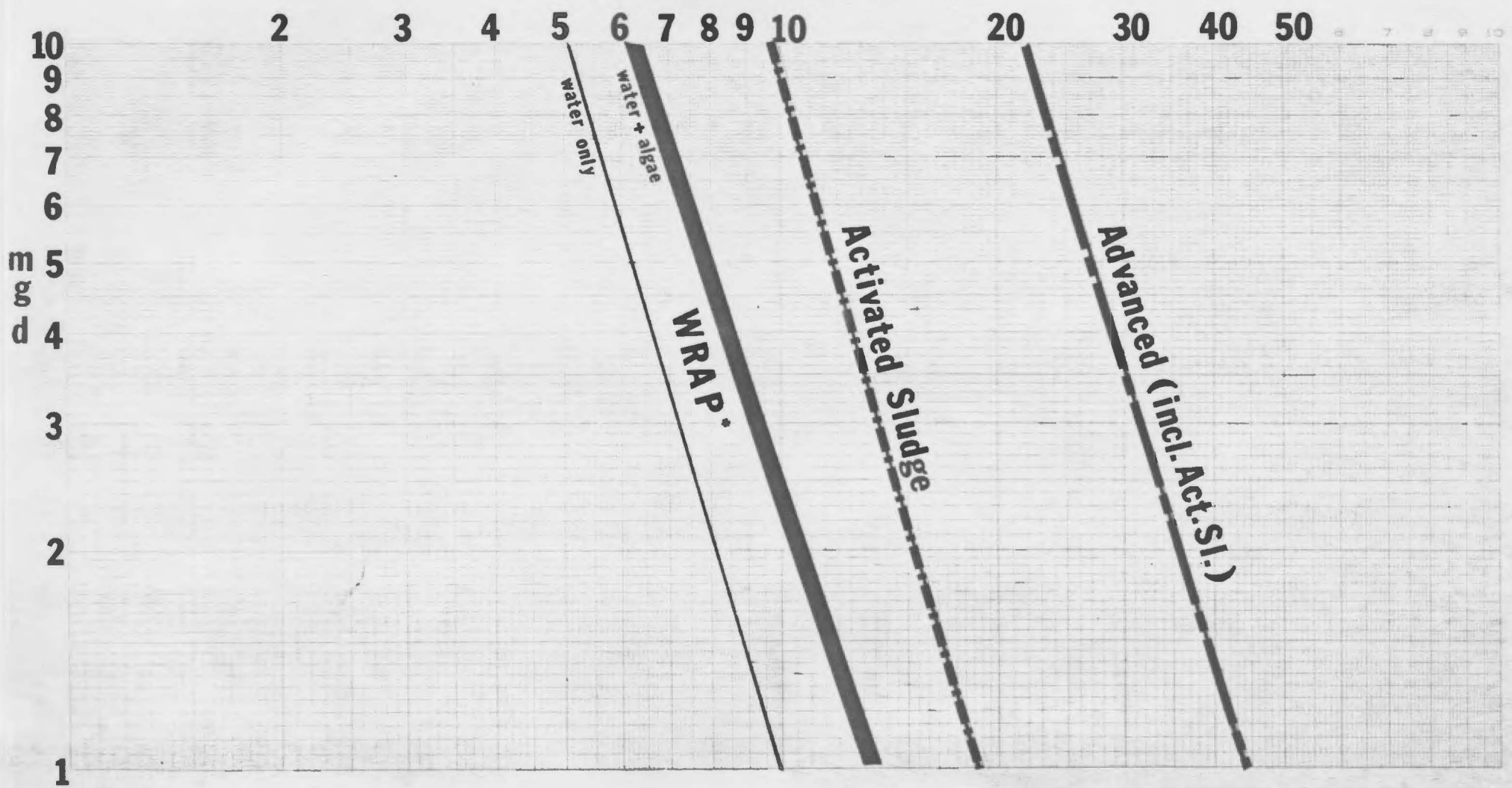


5. Capital Costs Millions of Dollars





6. Operating Costs Cents per 1000 Gallons



Summary

Basically, the multiple pond system allows loading rates to be increased two to four times that of conventional pond systems. This reduces land requirements to fifty percent or less of that normally required. The system does this with greater safety from odor production than conventional oxidation ponds. The efficiency of dissolved air flotation and the effectiveness of caustic disinfection complement the ponds to produce a performance which is comparable to that experienced at South Lake Tahoe in terms of BOD, phosphorous, nitrogen and coliform reduction. Projected costs run about 30 percent of those at Tahoe and are competitive to those of activated sludge.

The algae recovered has a potential value of \$100 or more per ton and an average of over one ton per million gallons is possible. (13)



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The WRAP Process

1985 Treatment for 1960 Costs

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THE WRAP PROCESS

Summary

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WRAP is a process of water reclamation - algae production.

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The process can achieve excellent nutrient reductions and is unique in achieving consistently negative coliform tests. Costs are lower than those of activated sludge processes.

The process consists of a multiple pond system followed by dissolved-air flotation. Several proprietary adaptations make the exceptional effluent quality possible.

Because of the favorable economics afforded by the recovery of a marketable by-product, the process can be provided to cities at a competitive cost, without grant funds and the attendant administrative problems and delays. Plants can be financed by means of a lease plan which negates bond elections.

In water-short areas of the country, costs to the city may be entirely recovered by resale of the effluent to industry.



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THE WRAP PROCESS

Summary

WRAP is a process of water reclamation - algae production. The process produces an effluent of very high quality which is suitable for recycling for many uses. The process provides an answer to meeting the Environmental Protection Agency's 1985 standards with the best cost-effective technology available. In addition to producing extremely low BOD and suspended solids levels, the process can achieve excellent nutrient reductions and is unique in achieving consistently negative coliform tests. Costs are lower than those of activated sludge processes.

The process consists of a multiple pond system followed by dissolved-air flotation. Several proprietary adaptations make the exceptional effluent quality possible.

Because of the favorable economics afforded by the recovery of a marketable by-product, the process can be provided to cities at a competitive cost, without grant funds and the attendant administrative problems and delays. Plants can be financed by means of a lease plan which negates bond elections.

In water-short areas of the country, costs to the city may be entirely recovered by resale of the effluent to industry.

Background

The years 1977 and 1985 are key points in the Environmental Protection Agency's drive to improve the quality of the nation's waters. By 1985 "zero discharge" is the goal. "Zero discharge" means an effluent quality which is equal to or superior to the quality of the receiving stream; a discharge which contributes no pollution.

In order to achieve this, a high degree of treatment of our wastewaters is mandatory.

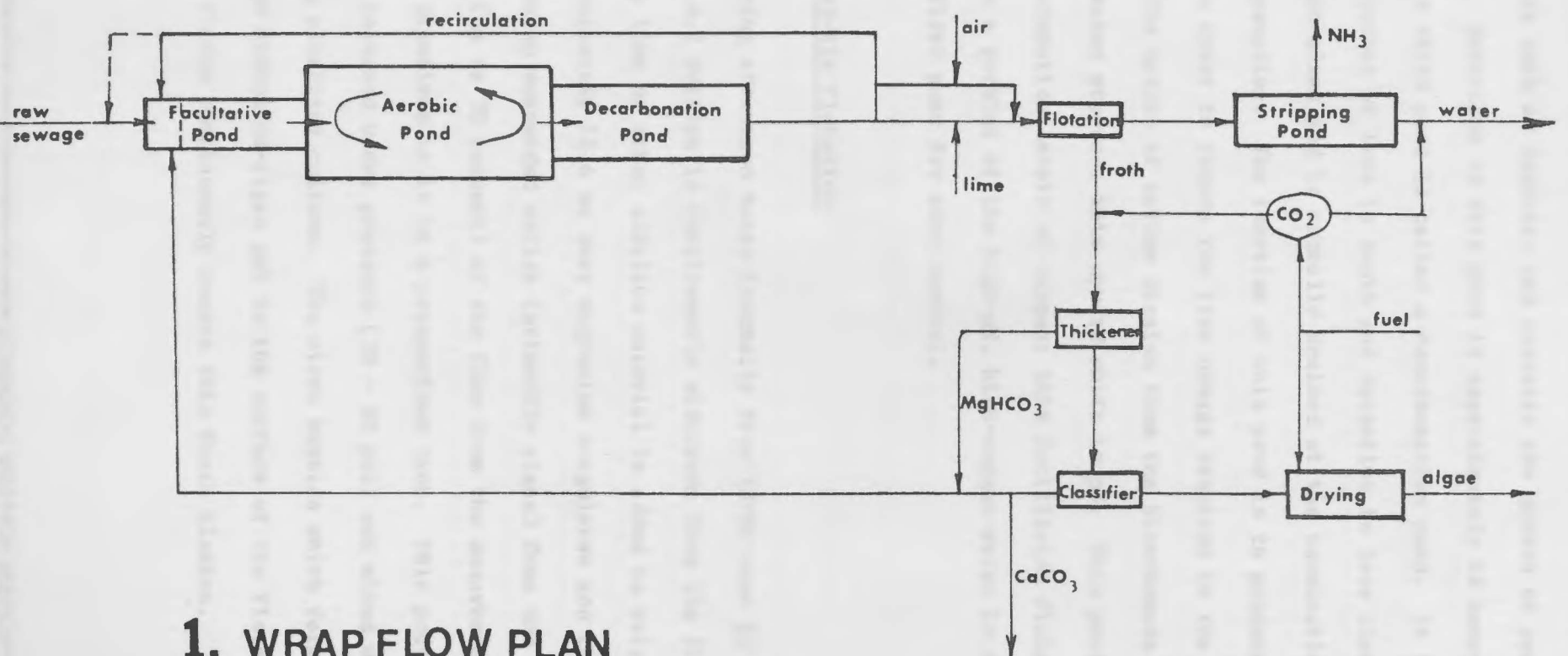
Processes which are presently being used, such as variations of activated sludge and extended aeration are not capable of producing effluents suitable for recycling without additional treatment steps and costs. Overall, the treatment requires removal of organics, nitrogen, phosphorous, bacteria, virus, and suspended solids. Multiple step processes such as the plant at South Lake Tahoe achieve the desired water quality, but at a cost which is virtually prohibitive.

WRAP achieves the desired water quality at an attractive cost.

The Multiple Pond System

The WRAP (Water Reclamation - Algae Production) process features several innovations as Figure 1 indicates. In its simplest configuration, raw sewage flows into the first of a series of three ponds. This first pond has an initial sludge holding section which is considerably deeper than the remainder of the pond. This deep section is upwards of ten feet in depth while the remainder of the pond is operated at a nominal depth of six feet. The overall loading rate on this pond area should range between 4 and 10 pounds of BOD per 1000 cubic feet. Organic waste materials are degraded into simpler organic intermediates and inorganic materials in this pond. The pond is largely anaerobic except for a zone near the surface and a considerable amount of photosynthetic activity occurs at the surface in warmer weather. This first pond is primarily effective through bacterial action and is called the facultative pond. This area may be loaded at 10 to 20 pounds per 1000 cubic feet in summer, but to allow for winter conditions a more conservative four pounds is normally used for a design basis.

The second pond is primarily effective through the activity of algae and is called the aerobic pond. This pond is approximately one foot in depth and is mixed periodically. It is designed to produce a relatively high-density culture of algae. Effluent from the initial pond flows into it and the algae culture rapidly starts to assimilate the inorganic and intermediate organic materials. The shallow depth allows adequate exposure to sunlight even when the culture has a high density of algae. Mixing provides improved availability of nutrients to the algae, helps keep pH values low, discourages the growth of



1. WRAP FLOW PLAN

predators such as daphnia, and prevents the growth of pests, such as midges. Detention in this pond is approximately 48 hours.

The third pond is called a decarbonation pond. It is operated at six inches or less in depth and detention is less than 8 hours. It is not mixed and is normally drained at the termination of each day's operation. The function of this pond is to produce a high pH value in order to reduce the lime dosage required in the flotation step. The uptake of carbon dioxide from the bicarbonate dissolved in the water produces this upward shift in pH. This pond also attains super-saturation levels of oxygen; this facilitates flotation. In addition a portion of the high-pH, high-oxygen water is recirculated to the first pond for odor control.

Dissolved-Air Flotation

During afternoon hours (normally from 12:00 noon to 9:00 or 10:00 p.m.) culture is continuously withdrawn from the final pond. Adequate lime or other alkaline material is added to raise the pH to approximately 11.4 so that magnesium coagulates and the voluminous gel picks up suspended solids (primarily algae) from the water. A portion (up to 30 percent) of the flow from the decarbonation pond has air dissolved in it in a pressurized tank. This portion of the flow is released under pressure (30 - 60 psi) and mixed with the incoming alkalized culture. The micro bubbles which form, buoy this magnesium hydroxide-algae gel to the surface of the flotation tank. Skimmer blades continuously remove this froth blanket.

Final Water Treatment

Underflow water goes to a stripping basin where it is retained for approximately 12 hours to effect sterilization and sprayed into the air to allow ammonia to escape. The water is then recarbonated to pH 9.0 to 9.5 for stabilization. Finely divided calcium carbonate precipitates and is separated by sedimentation. This results in a sparkling clear, soft, stable, sterile water which should average approximately 1.0 mg/l BOD, 0.1 mg/l total phosphate and show a nitrogen reduction averaging over 80 percent.

By-Product Handling

The froth skimmed from the flotation unit is then reacted with carbon dioxide to neutralize the magnesium hydroxide. Following gravity thickening, calcium carbonate is centrifugally classified from the algae. The algae is dewatered either by centrifuge, filter, or dewatering beds and dehydrated to a final product. The magnesium-rich solution which is separated during thickening and dewatering may be recycled to maintain an optimum magnesium coagulant level and improve buffering of the culture or it may be routed to an evaporation pond where magnesium carbonate may be recovered as a by-product.

Process Performance

ERA has operated its Lubbock pilot plant over a period of four years. A number of continuous evaluational test runs have been performed with the plant. The table which follows lists the results achieved during a continuous test run of over four months (April through August) in 1973.

TABLE I

Average Pilot Plant Performance

	In mg/l	Out mg/l	Percentage Reduction
BOD ₅	412	1.8	99.5
Suspended Solids	343	6.3	98.2
Total Phosphorous	16	0.04	99.6
Ammonia Nitrogen	34	1.3	96.2
Total Hardness	260	85	67

Although coliform tests were not performed during this particular run, previous tests using the membrane filter technique showed counts of zero coliforms, without exception. In addition the process does produce a reduction in total dissolved solids by virtue of the uptake of carbon dioxide from dissolved bicarbonate and precipitation of calcium and magnesium. Degradation of organics provides a source of carbonate which enhances the softening action of the process regardless of whether the original hardness was carbonate or noncarbonate.

WRAP Costs

With today's rapidly escalating costs it is difficult and hazardous to quote a generalized cost much less a specific cost for more than 90 days ahead. For that reason only comparative costs will be presented below.

In this specific example a city of approximately 30,000 in Southwestern United States is building a new complete-mixed activated sludge plant. Estimated cost of the plant in July 1974 was \$4.7

TABLE I
Average Pilot Plant Performance

Parameter	In mg/l	Out mg/l	Percentage Reduction
Total Hardness	350	85	75
Ammonia Nitrogen	34	1.3	96.2
Total Phosphorus	16	0.04	99.8
Suspended Solids	207	4.3	98.3
BOD ₅	415	1.8	99.6

Although column tests were not performed during this particular run, previous tests using the membrane filter technique showed counts of zero coliforms without exception. In addition the process does produce a reduction in total dissolved solids by virtue of the uptake of carbon dioxide from dissolved bicarbonate and precipitation of calcium and magnesium. Degradation of organics provides a source of carbonate which enhances the softening action of the process regardless of whether the original hardness was carbonate or noncarbonate.

WRAP Costs

With today's rapidly escalating costs it is difficult and hazardous to make a projected cost much less a specific cost for more than a year ahead. The first major cost comparative study will be presented below.

In this study a summary of the estimated 30,000 in Southeastern United States is being a new wastewater treatment plant. Estimated cost of the plant in July 1974 was \$1.5 million.

million dollars. ERA estimates the cost of a WRAP plant to serve the same city at \$2.0 million dollars. In both cases, the projected cost of operation and maintenance is approximately 8 percent of capital costs annually. The table below summarizes comparative costs.

COMPARATIVE COSTS

	Complete Mix Activated Sludge	WRAP
<u>Plant Cost</u>	\$4,200,000	\$2,000,000
<u>Net Cost After Federal Grant</u>	1,050,000	2,000,000
Annual Debt or Lease Cost	94,000 ¹	240,000 ²
Annual Operation and Maintenance	376,000	160,000
<u>Total Annual Cost</u>	\$470,000	\$400,000 ³

- ¹ Municipal Bonds - 25 years
- ² 20 Year Lease - after 20 years plant is paid out and lease adjusted.
- ³ WRAP water is suitable as industrial cooling water without further treatment. At 4 MGD flow, 25 cents per 1000 gallons would cover all WRAP costs.

The above comparison becomes even more impressive when we consider that no bond election is required, no federal grant funds are used and no new facilities are required for 1985 requirements (as will be the case with the activated sludge plant). The total cost for a WRAP plant, to the city and taxpayers, is far less even when the administrative costs of a federal grant program are not taken into consideration,

Lubbock WRAPS it up

Treatment costs with Water Reclamation-Algae Production are claimed competitive with activated sludge process "while providing excellent results."

MAKE ALGAE and other natural processes work for you.

This is the message coming from Lubbock, Texas where an algal-chemical wastewater treatment process has been undergoing pilot testing at the City's sewage treatment plant.

The new process, dubbed WRAP (Water Reclamation-Algae Production), features several innovations as Fig 1 indicates.

In its simplest configuration, raw sewage flows into the first of three ponds. This first pond may be operated at a depth ranging from five to seven or more ft and is largely anaerobic except near the surface of the water. In it organic waste materials are degraded into simpler organic intermediates and inorganic materials. A limited amount of photosynthetic activity occurs at the surface in warmer weather. This pond is designated a facultative pond. Detention time in it may vary from six days in summer to as much as 12 days in winter.

The second pond, is an aerobic pond, approximately one ft deep, mixed periodically. It is designed to produce a relatively high-density culture of algae. Effluent from the facultative pond flows into it and the algae culture rapidly starts to assimilate the inorganic and intermediate organic materials. The shallow depth allows adequate exposure to sunlight even when the culture has a high density of algae. Mixing improves availability of nutrients to the algae; helps keep pH values low; discourages the growth of predators such as daphnia; and prevents the growth of pests, such as midges. Detention in this pond is approximately 36 to 48 hours.

The third pond, a decarbonation pond, is operated at six in. or less in

depth and about four hours detention. It is not mixed and is normally drained at the termination of each day's operation. Its function is to produce a high pH value in order to reduce the lime dosage required in the flotation step. The uptake of carbon dioxide from the bicarbonate dissolved in the water produces this upward shift in pH. This pond also attains supersaturation levels of oxygen to facilitate flotation.

Culture continuously withdrawn

Normally, from 12:00 noon to 9:00 or 10:00 p.m., culture is continuously withdrawn from the decarbonation pond. Adequate lime or other alkaline material is added to raise the pH to approximately 11.4 so that magnesium coagulates and the voluminous gel picks up suspended solids (primarily algae) from the water. Up to 30% of the underflow effluent from the flotation unit has dissolved in it in a pressurized tank. This portion of the effluent is released under pressure (30 to 60 psi) and mixed with the incoming alkalinized culture. The micro bubbles which form, buoy the magnesium hydroxide-algae gel to the surface of the flotation tank. Skimmer blades continuously remove this froth blanket.

Underflow water goes to an alkaline holding basin where it is retained for one hour or more, to effect sterilization. The water is then recarbonated to pH 9.0 to 9.5 for stabilization. Finely divided calcium carbonate precipitates and may be separated, either by sedimentation or filtration. This results in a clear, soft, stable, sterile water which should average approximately 1.0 mg/l BOD, 0.1 mg/l total phosphate and show a nitrogen reduction averaging 80%.

The froth skimmed from the flotation unit is then reacted with carbon dioxide to neutralize the magnesium hydroxide. Following gravity thickening, calcium carbonate is centrifugally

classified from the algae. The algae is dewatered either by centrifuge, filter, or dewatering beds and dehydrated to a final product.

The magnesium-rich solution which is separated during thickening and dewatering can be recycled to maintain an optimum magnesium coagulant level and improve buffering of the culture or it can go to an evaporation pond where magnesium carbonate can be recovered as a by-product.

The flotation foam can also be stored for 12 hours or more, allowing the alkaline condition to hydrolyze the protein from the algae. Calcium carbonate is then centrifugally classified; the decant water is acidified to pH 4.5 which dissolves magnesium hydroxide and precipitates protein. The protein is dewatered by filter or centrifuge and dried; the magnesium-rich water then is recycled or evaporated for magnesium recovery.

During the first year of pilot plant operation, primary clarified waste was used exclusively and the plant operated quite consistently with little trouble. In the spring of 1971 the plant pickup point was moved from the outlet of the City of Lubbock's primary clarifier to the raw sewage distribution box. Of course, much larger quantities of sludge were then picked up. Within two weeks the operating characteristics of the pilot plant began to change radically. In the decarbonation pond pH levels dropped sharply and coagulation of the suspended algae became extremely difficult. Decarbonation pond pH ranged between 8 and 9. Massive dosages of lime produced only limited coagulation. Tests with alum, ferric sulfate and sodium hydroxide also indicated that massive dosage was required for coagulation.

Three procedures prove effective

Three procedures were found to be effective in overcoming the problem. First, the recycle of unrecarbonated

BY JAY E. ORT, Ecological Research Associates, Lubbock, Texas.



WRAP SYSTEM uses facultative pond (upper right) where algae assimilate degraded organic material in wastewater. It then flows into aerobic pond (center) and finally to decarbonation pond (lower left).

effluent was used which gave two beneficial results. It provided buffering in the facultative pond and it was apparently helpful in balancing bacterial activity. The problem stemmed from the abrupt increase in sludge loading in the facultative. Just as shock loadings tend to upset digester operation by the increase in acid fermentation compared to methane fermentation, so did the shock loading upset methane production in the pond. The excessive production of organic acids, obviously carried over to the decarbonation pond and kept pH values low. These same organic acids also chelated the various coagulants used and made the massive dosage necessary. Second, magnesium salt was introduced to the facultative pond. This provided excess magnesium to overcome the chelating effect of the organic acids and provided additional buffering capacity. The magnesium addition resulted in more effective coagulation at lower lime dosages. Third, a portion of the alkaline decarbonation pond water was recirculated after a high pH was again attained. This provided buffering and helped keep the fermentation process balanced.

Just as with digester operation, the key to smooth operation is a relatively uniform feed rate. An abrupt change, such as a shift from primary to raw sewage, is adequate to upset the fermentation reaction in the facultative pond and should be avoided.

The multiple pond system allows much higher loading rates and reduced land requirements compared to simple ponding operations. This is primarily a result of increased oxygen resources and their more efficient use in this system (Fig 2).

Odors can be avoided

The advantages of anaerobic ponds are offset by the production of odors

which prohibit their use near populated areas. When anaerobic ponds are used in combination with shallow ponds as oxygen generating basins for recirculation, very high loading rates can be employed without odor problems.

The shallow ponds can generate as high as 700 lbs of oxygen per acre per day. Each pound of algae cells generated is accompanied by the generation of about 1.6 lbs of oxygen. With a retention of just under two days in the shallow ponds, algae density jumps from under 50 mg/l to as high as 800 or 900 mg/l under favorable weather conditions. For design purposes the more conservative figure of approximately 150 lbs per acre should be used. By recirculation of a small portion of the oxygen-rich, alkaline, shallow-pond culture, a film of oxygen and alkalinity can be maintained on the surface of the highly loaded first pond. This film will control odors.

The odor control capability is largely the result of the alkaline nature of the film. Odors from anaerobic lagoons are primarily from the acid fermentation reaction which produces organic acids, and such odorous compounds as indole, skatol, cadaverin and hydrogen sulfide. The odors indicate an imbalance between acid-forming and methane bacteria. These compounds can escape only when surface conditions are acidic.

The high absorption capacity of the shallow ponds for solar energy keeps pond temperatures high during the day. In addition, the oxygen generation produces values of three to four times saturation in the shallow culture. These two factors usually make the recirculation water less dense than the water of the first pond and facilitate the formation of a surface film, during daylight hours. In cold weather the shallow pond culture may be cooler

than the deep pond and recirculation of the denser material would disturb the methane fermentation process. For this reason, recirculation is not recommended in cold weather.

Even without circulation, the deep ponds will not generate objectionable odors in cold weather, if proper design considerations are used. If the fresh sewage inlet to the deep ponds is near the surface of the ponds and the inlet is designed for low turbulence, the warm fresh sewage will form a surface layer on the pond. This layer will be nearly neutral in pH and will keep odors from escaping into the atmosphere.

Placing the facultative pond outflow at the proper depth can also be beneficial. A depth of between approximately 12 and 24 in. below the surface of the deep initial pond is advisable. At this depth only a small portion of any photosynthetic growth is transferred to the aerobic ponds. This encourages a build-up of algal activity on the surface and reduces the need for recirculation water in warm weather or fresh sewage film in cold weather.

pH values reach 11

The decarbonation pond is operated at about six in. of depth, compared to five to seven ft in the first pond and approximately 12 in. in the middle pond. The primary function of this pond is to allow algal activity to elevate the pH of the water and in so doing reduce lime requirements during phase separation. By the time culture reaches the decarbonation pond much carbon from organic sources has been depleted and bacterial activity is much reduced because of environmental factors in the very shallow pond. In the decarbonation pond the primary source of carbon for algal growth is the bicarbonate in the water. Each CO_2 assimilated from bicarbonate leaves one hydroxyl ion. This produces a rise in pH and in the Lubbock area it is possible to achieve pH values of 11 from March through October.

In winter, pH values normally run between pH 9.0 and 10.0. Such pH values result in a reduction in lime dosage which for many waters would amount to a savings of 60% to 80%. In the Lubbock pilot plant pH levels of 11.2 are not uncommon in favorable weather. The high pH values are accompanied by supersaturation of the water with oxygen and a rise in temperature.

If wind action is present, autofloculation and flotation of algae will occur in this pond area. In a properly designed system a number of incidental benefits can be derived from the decarbonation pond. With proper capacity the pond can produce a culture which is nitrogen limiting and can pro-

duce high levels of nitrogen reduction.

The high pH coupled with wind action can lose significant amounts of ammonia nitrogen to atmosphere; and, it produces precipitation of calcium phosphate and under certain conditions ammonium calcium phosphate. In addition, significant reduction in coliforms results from exposure to ultraviolet light, extracellular algal products and high pH. The high concentrations of algae cells and the associated oxygen generation assure a final water which is high in dissolved oxygen.

During operations in 1970, precipitation trials were run using supplemental phosphate in the decarbonation pond to ascertain the feasibility of attaining high levels of ammonia removal by precipitation of ammonium calcium phosphate, which is relatively insoluble.

This test indicated that, while there is considerable merit in an approach which could remove both nitrogen and phosphorous in one chemical reaction, control is difficult and additional refinement is required.

Decide not to fight nature

The initial design on the pilot plant included a tube settler-equipped sedimentation tank. During operation, the tube settlers worked very well during the morning, but in the afternoon problems developed with the actively photosynthesizing algae culture becoming supersaturated with oxygen. Then, in spite of anything that was done to prevent it, the algae would tend to float and would break through the tube settlers and rise to the surface of the sedimentation tank. Rather than fight this phenomenon it was decided to cooperate with the natural tendency and convert to a flotation process.

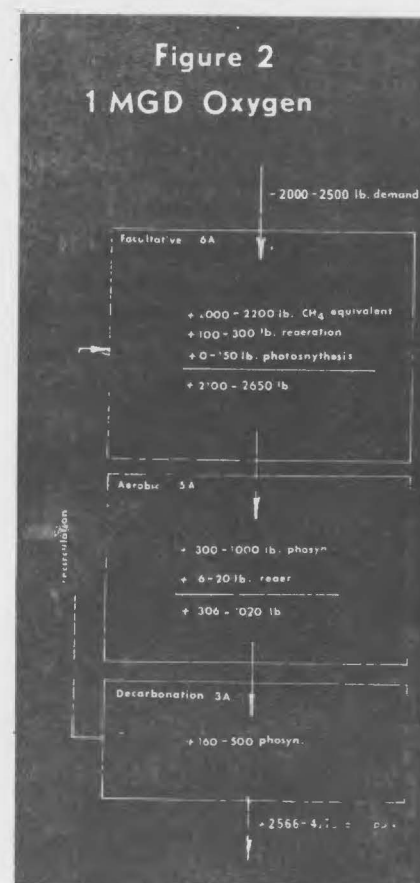
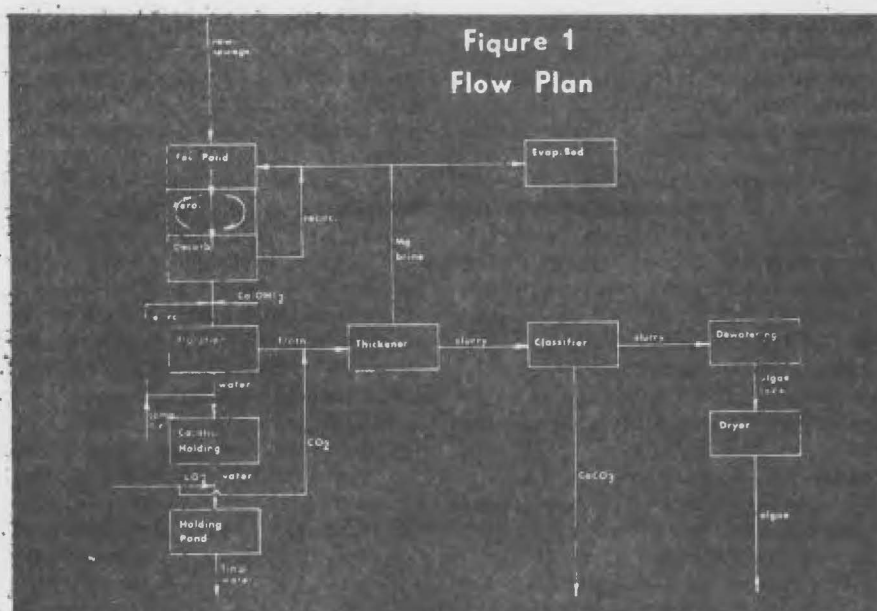
Various flotation configurations were tried and flotation was found to be a very effective technique for algae separation. The vertical tank which was converted from sedimentation worked reliably but was considered less than optimum for scale-up purposes. A horizontal pilot unit which was more efficient but also more critical was designed and operated. The horizontal design is considered more practical for scale-up process.

Two pressurized air configurations were also tried. Direct full flow pressurization is very effective but involves high pumping costs and potential maintenance problems. Partial recycle of underflow water is also quite effective and has much lower pumping requirements and potentially less maintenance.

Phase separation is basically a modified cold-lime process. Traditionally, cold-lime treatment has used sedimentation tanks for phase separation with detention times of up to two hours. Through the use of dissolved air flotation a detention time in the flotation tank of only 12 minutes is required.

Much of the time, supplemental dissolved air is not required because of the high oxygen content of water coming from the decarbonation pond. Supersaturation oxygen forms micro bubbles after undergoing a pressure change as it passes through the feed pump. Supplemental air is supplied by pressurizing up to 30% of the flotation tank effluent to about 50 psi and introducing the pressurized water into the flotation tank influent. The supplemental dissolved air allows the flotation unit to operate efficiently and produce a relatively high quality effluent regardless of weather conditions.

Because pH levels from the decarbonation pond are highest during the late



morning hours through sunset, the flotation unit is operated only during these hours.

Method compares with chlorination

After passing through the flotation tank the underflow water is held for at least one hour before being recarbonated. The delay in recarbonation produces a water that is essentially sterile. The high pH virtually hydrolyzes all bacterial and virus cells.

The results achieved compare favorably with chlorination on wastewater effluents.

Froth which has been skimmed from the flotation unit consists primarily of algae cells and calcium carbonate enmeshed in magnesium hydroxide gel. In order to have a by-product with potential commercial value it is necessary to separate calcium carbonate and magnesium hydroxide from the algae cells.

The denser calcium carbonate is readily separated from the algae and magnesium by centrifugal classification. Pilot work showed excellent separation at surprisingly high throughput rates on a solid bowl centrifuge.

Prior to classifying the calcium carbonate it has been found to be beneficial to react the froth with carbon dioxide, converting magnesium hydroxide to the soluble bicarbonate and facilitating classifying. Gravity thickening is also advisable prior to classifying.

1-PILOT PLANT PERFORMANCE

	In	Out	Reduction
BOD ₅	280-450	0-3	99-100%
COD	700-960	20-64	92-97%
Total phosphorous	14-18	0.02-0.06	99.4-99.9%
Total nitrogen	72-82	2.0-29.6	64-97%*
Total coliforms	10-30x10 ⁶ /100 ml	zero	100%
Enterovirus	1844/gal.	zero	100%
Total hardness	260-290	28-132	60-90%
Silica	45-55	4.6-5.2	89-92%
Suspended Solids	240-360	0-50	86-100%*

*Somewhat less than optimum due to pilot plant design limitations.

2-MATERIAL FLOWS-TYPICAL RANGE

	Unfiltered COD mg/l	P mg/l	N mg/l	Total Algal Solids
Raw sewage	400/1000	10/20	40/100	0
Facultative pond eff.	200/600	10/20	30/80	50 mg/l
Aerobic pond eff.	200/600	5/15	20/50	100-800 mg/l
Decarbonation pond eff.	200/800	2/12	5/30	150-1000 mg/l
Recarbonation classifier basin eff.	15/65	0.01/0.10	1/25	nil
Classifier	---	---	---	2-6%
Thickener-steeping tank	---	---	---	4-8%
Dewatering centrifuge	---	---	---	16-26%
Drier	---	---	---	90-92%

ing. The algae are next dewatered with magnesium being carried in the solution. Dewatering may be by centrifuge, filtration, or beds. The bicarbonate can then be recycled to provide buffering capacity in the pond system and magnesium can be maintained at an optimum level as the primary coagulant and also be beneficial in odor control. After dewatering, the algae are ready for dehydration and storage.

In working with the froth, it was found that if the materials were allowed to stand at a high pH for a number of hours before dewatering, the algae cake came through with very low protein value. An analysis of the extracted water showed a high Kjeldahl nitrogen level, indicating that hydrolysis of the protein had occurred. Acidifying the hydrolyzed protein to pH 4.5 produces precipitation and a potentially valuable refined product.

What are the results?

Table I lists the performance values recorded at the pilot facility and are those obtained by independent testing programs including a continuous run of nearly two months in 1971.

It should be noted that the suspended solids from the pilot plant are almost entirely calcium carbonate, reflecting a design deficiency after recarbonation; this can readily be corrected in scale-up.

Improved nitrogen and COD removal can be achieved through incorporation of several design factors developed in the pilot facility. COD removal in the process is highly dependent upon the capacity of the facultative area. At high throughputs, effluent COD ranges in the 50's and 60's. With throughput reduced approximately 30%, COD's dropped into the 30's and 40's. These values, it should be noted, are from influent levels between 800 and 1000 mg/l. Lower throughputs

have yielded COD values in the 20's. The minimum COD attainable with the system is thought to be approximately 14 to 15 mg/l because of metabolic by-products from the algae. The lag time between the change in throughput rate and reduction in COD was found to be four to six days during summer operations of the pilot plant.

Effluent nitrogen varies with throughput. No lag time is apparent in the change in effluent nitrogen indicating that decarbonation pond capacity is critical in nitrogen removal. With adequate decarbonation capacity 90% nitrogen reduction is possible.

The various wastewaters amenable to treatment by the system include domestic sewage, animal wastes, meat-packing wastes, certain other food-processing wastes and any industrial wastes that are essentially organic in nature and primarily water-borne.

Table II lists the more important material flows for the system: COD representing organic carbon; phosphorous; nitrogen and algal solids concentration.

How much does WRAP cost?

Total treatment costs for a WRAP plant are competitive with those of activated sludge. Projected costs for a 7.5 mgd plant run about 13¢ per 1000 gal.

Table III lists estimated costs for a typical four mgd facility such as is presently under design for Clovis, New Mexico. So long as land values do not exceed approximately \$12,000 per acre, the capital costs will be in line with those of activated sludge.

Although the algal by-product normally has a protein content of 40% to 50% and is superior in biological value to soybean meal, market development is still a hurdle, so no value is given to algal recovery.

The reduced hardness and silica in

3-ESTIMATED 4 MGD COSTS

Capital Costs	
Pond system	\$ 375,000
Flotation equipment	325,000
Accessory items	250,000
Land @ \$1000/A	75,000
Total	\$1,025,000
O & M Costs—Annual	
Labor @ \$3.50/hr. Av.	\$ 51,100
Power @ 1.5¢/kwh	13,200
Fuel @ 40¢/mm BTUS	12,000
Lime @ \$25/T	22,800
Maintenance (3% of capital)	28,500
O.H. @ 25% of labor	12,750
Sub-total	\$ 140,350
Debt service 20 yrs. @ 6%	83,000
Total	\$ 222,350

the product water could be an economic factor because of its potential use as cooling water by industry in hard water areas. □ □

NOTE: Portions of the process described in the article are covered under Patents 3,521,400 and 3,645,040. Other patents pending.

ACKNOWLEDGEMENTS

All funds came from private individual sources. Assistance in the form of land for constructing the pilot plant was provided by The City of Lubbock. The City also provided some of the water quality testing work.

The author is personally grateful for the moral and financial support provided by these several private sources.

KEY WORDS

Plant design; Organic wastes; Wastewater treatment; Eutrophication; Research; Algae.

REPORT ON

THREE WEEK OPERATIONAL RUN OF THE WRAP SYSTEM
PILOT PLANT AT LUBBOCK, TEXAS

Prepared For

ERA, Inc.

by

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DAN M. WELLS, PH.D.
CONSULTING ENGINEER
2512 SLIDE ROAD
LUBBOCK, TEXAS 79407
806-SW5-5313

May 14, 1974

ERA, Inc.
1638 Main
Lubbock, Texas

Gentlemen:

Enclosed is a copy of the final report of our monitoring program on the WRAP system pilot plant at the Lubbock, Texas, wastewater reclamation plant.

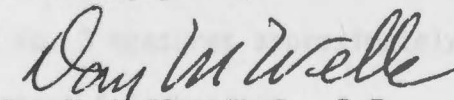
We are delighted to be able to report to you that the performance of the plant during the three week observation period was far above our expectations. While no extensive period of freezing weather occurred during the monitoring program, the short periods of freezing temperature that did occur did not appear to have any adverse effect on the system's operation.

I can think of no reason to believe that a larger scale system designed on the basis of your pilot plant operation would not give similar results. I look forward to seeing a full-scale plant in operation in the foreseeable future.

We appreciate the opportunity of performing this service for you, and of seeing the system in continuous operation for a significant length of time.

Please advise me if we can be of any further service to you.

Sincerely yours,


Dan M. Wells, Ph.D., P.E.
Consulting Engineer

Enclosures: (1) Final Report
(2) Statement



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The WRAP system is a waste treatment system designed to provide a high degree of treatment to wastewater at low cost, and to utilize the nutrients contained in the wastewater for growing algae. The algae, in turn, will be harvested and utilized for livestock feed or other purposes.

DESCRIPTION OF PLANT

The pilot plant that was monitored in this study consists of three ponds, followed by an algae separation system.

Pond No. 1 is about 20 feet wide and 140 feet long, with an approximate depth of 3.5 feet. A sump approximately 8 feet deep and 10 feet wide was dug at the influent end of the pond, and a submerged dam approximately 2.8 feet high is provided across the middle of the pond.

Pond No. 2 is about 20 feet wide and 165 feet long. Approximate water depth is 15 inches at the influent and 10 inches at the effluent end.

Pond No. 3 measures approximately 38 x 20 feet and has an average depth of about 6 inches.

Ponds 2 and 3, especially 3, support very luxuriant growths of algae, and because of the excessive algal growth in pond 3, a very high pH generally occurs in the afternoon. Effluent from this pond is run through a flotation separation operation, with the algae removed being



dewatered further by a filter press. The final effluent from the system is generally clear, colorless, and odorless.

During the operational run, settled sewage was picked up by a pump just below the overflow weir of the primary sedimentation basin of the trickling filter segment of the Lubbock wastewater reclamation plant, and pumped into the WRAP pilot plant at a steady rate of approximately 9.4 gallons per minute throughout the day. The algae separation system was operated at a rate of about 29 gallons per minute, from about 11:00 a.m. until about 7:00 p.m. each day. On Sundays, the effluent from the third pond was diverted back to the city's sewage treatment rather than being run through the algae separation step.

The total volume of the three ponds is approximately 99,000 gallons, and the average detention time in the entire system is about 7.3 days.

Total surface area of the three ponds in use is approximately 6,860 square feet or 0.1575 acres. Hence, the hydraulic loading rate was approximately 86,000 gallons per acre per day.

MONITORING SYSTEM

The system was monitored by means of two automatic sampling devices. Influent into the plant was directed into a bucket of approximately 5 gallons capacity, and a quarter-inch diameter plastic tubing was led into the bucket. The tubing was connected to a Sigmamotor pump, which was controlled by a timer set to turn the pump on for a period of approximately one minute at 15 minute intervals throughout the day. This apparatus collected approximately one gallon of influent per day. The samples were collected in a single unrefrigerated plastic jug, which was picked up at approximately 7:00 p.m. each day.



The effluent from the plant was collected by using an automatic sampler that collected a 300 ml sample once each hour while the plant was in operation. The eight samples thus collected were combined and considered to be a composite sample of the entire effluent.

In addition, grab samples of raw influent to the Lubbock wastewater reclamation plant and to the WRAP system were collected at approximately 7:00 p.m. each day.

Since the flow rate to the WRAP system was constant, and since equal volumes of influent to the plant were collected at 15 minute intervals throughout the day, the composite sample thus collected is believed to be a truly representative composite sample of the influent to the plant. Also, the hourly samples of WRAP system effluent collected are believed to be representative of the true output of the system, since no significant difference in quality occurred during the period of observation.

It should be pointed out that, while the plant was monitored for three weeks, results are reported only for the last two weeks of operation. The reason for this decision is that the plant had not been in continuous operation before the monitoring program was started. Thus, if ideal flow conditions existed through the plant, the effluent obtained during the first week of operation would be water that had been stored in the system for an undetermined length of time. In fact, no significant difference in either influent or effluent quality was observed during the entire three week operation, but it was felt that deletion of the first week's result would give a more accurate picture of the system's ability to treat wastewater.



ANALYTICAL PROCEDURES

With the exception of dissolved solids, all analyses were performed in accordance with procedures detailed in Standard Methods for the Examination of Water and Wastewater, 13th Edition. Dissolved solids concentration were determined by using a dissolved solids meter, which has been found to yield very reliable and repeatable results. Effluent BOD samples were seeded with influent to the WRAP system.

RESULTS OBTAINED

Detailed results obtained in the program are shown in Table 1. It will be observed in Table 1 that total solids and dissolved solids are very nearly equal in many cases. Where this condition is reported to exist, it is believed that the dissolved solids shown are more likely to be accurate than are the total solids.

BOD₅ values shown are the concentrations as determined in the laboratory. Influent BOD₅ concentrations shown are undoubtedly somewhat lower than the actual concentrations because of degradation that occurred between the times the samples were collected and the times they were analyzed. The sampling pump collected a sample at 15 minute intervals, but the samples were stored in an unrefrigerated container until approximately 7:00 p.m. each day. Therefore, the average time between collection and analysis for all influent samples was 12 hours, and it appears likely that all BOD₅ concentrations shown would be more accurate if they were taken to be 90 percent of the actual BOD₅ concentrations. This, obviously, would increase all BOD₅ removal efficiencies somewhat, unless the efficiency is already shown to be 100 percent.

TABLE 1. RESULTS OF TWO WEEKS OPERATION OF THE WRAP SYSTEM AT LUBBOCK, TEXAS WASTEWATER RECLAMATION PLANT DURING THE PERIOD MARCH 27, 1974 THROUGH APRIL 9, 1974.

Date	Sample	pH	Temperature °C	Concentrations Expressed in Mg/l						
				COD	BOD ₅	Total Solids	Dissolved Solids	Total N	Total P	Hardness
3-27-74	Influent	7.5	21	454	141*	-1	1700	27.6	17.0	300
	Effluent	8.8	21	91	4	-	1400	15.5	0.01	72
	% Removed			80	97		18	44	99.9	76
3-28-74	Influent	7.6	22	472	82*	1590	1316	25.7	11.8	306
	Effluent	9.4	21	110	3	1288	995	15.5	0.03	108
	% Removed			77	96	19	24	40	99.7	65
3-29-74	Influent		21	No sample because of power failure						
	Effluent	10.5	20	109	1	1341	1318	12.7	.14	124
	% Removed									
3-30-74	Influent	7.2	22	405	103*	1649	1521	15.0 ²	14.2	327
	Effluent	10.5	22	130	4	1355	1356	13.4 ²	.04	104
	% Removed			68	96	18	11	11	99.7	68
3-31-74	Sunday - No samples taken									
4-1-74	Influent	7.7	22	281	94*	1525	1492	18.9 ²	14.0	318
	Effluent	10.9	21	117	5	1426	1369	8.9 ²	.03	140
	% Removed			58	95	6	8	53	99.8	56
4-2-74	Influent	7.7	20	424	96*	1575	1533	16.6	13.8	308
	Effluent	10.5	18	126	2	1430	1371	9.1	1.17	72
	% Removed			70	98	9	11	45	92	77
4-3-74	Influent	7.9	20	506	90*	1806	1498	24.4	8.1	346
	Effluent	11.1	17	119	1	1374	1354	9.9	0.04	80
	% Removed			76	99	24	10	59	99.5	77
4-4-74	Influent	7.1	21	674	99*	1774	1521	38.4	15.0	330
	Effluent	10.4	13	137	1	1451	1424	11.8	0.03	48
	% Removed			80	99	18	6	69	99.8	85
4-5-74	Influent	7.4	21	777	174*	1822	1510	19.3	13.0	308
	Effluent	11.0	16	134	2	1444	1418	8.4	0	64
	% Removed			83	99	21	6	56	100	79
4-6-74	Influent	7.6	21	598	97*	1693	1493	18.9 ³	.4	300
	Effluent	10.4	20	108	0	1432	1413	7.1 ³	.4	50
	% Removed			82	100	15	5	62	-	83
4-7-74	Sunday - No samples taken									
4-8-74	Influent	7.3	22	425	85*	1723	1519	27.7	14.0	320
	Effluent	9.5	18	131	0	1440	1422	11.0	0.03	40
	% Removed			69	100	16	6	60	99.8	88
4-9-74	Influent	7.8	21	722	94*	1682	1468	23.4	11.8	330
	Effluent	9.4	19	134	2	1429	1403	10.9	0.07	50
	% Removed			81	98	15	4	53	99.4	86

¹Incompatible Results.²Organic N Not Included.³Nitrate N Not Included.⁴Samples Discarded Accidentally.

*BOD₅ values shown are thought to represent approximately 90 percent of the true BOD₅ of the samples because samples were stored an average of 12 hours without refrigeration before being analyzed.

Assuming the reported BOD_5 concentrations are actually 90 percent of the true value, the total BOD_5 loading to the system was approximately 13.26 lbs per day or 84.2 lbs of BOD_5 per surface acre per day. At this loading rate, as shown in Table 1, the plant is extremely efficient in removing BOD, COD, phosphorus and hardness. In addition, more than 50 percent of the total nitrogen in the influent to the plant was removed, and total and dissolved solids were reduced to a significant extent.

Bacteriological analyses, including total plate counts and coliform counts, were performed once during each week of the three week testing period. In every instance, no coliform bacteria were found in the WRAP system effluent, although counts as high as 70,000/ml were obtained in the influent. During the first week of testing, total plate counts revealed three non-coliform bacteria per ml in the plant effluent, but none were found during the final two weeks of testing. The low count during the first week may be attributable to the lengthy time of exposure of a portion of the effluent to the atmosphere before the plant was started operating on a continuous basis.

While no prolonged freezing temperatures occurred during this test, low minimum temperatures of 38°, 35°, 32°, and 42°F occurred on April 3, 4, 5, and 6, respectively. Influent and effluent temperatures shown in Table 1 are 7:00 p.m. daily temperatures, and it is apparent that the low temperature of 13°C (55°F) did not result in any decrease in efficiency of the system. It is undoubtedly true that the minimum temperature of water in the system was less than 13°C on the mornings of April 4 and 5.

The BOD_5 concentrations shown for the composite samples of influent to the plant (effluent from a primary treatment system) seem to be

inordinately low, even when they are adjusted by being divided by 0.9 to account for degradation that occurred after collection. This apparent inconsistency can be explained by the fact that the plant was fed at a constant rate on a 24 hour per day basis. Neither the volume of flow to the city's wastewater reclamation plant nor the concentration of BOD_5 in the flow remain constant throughout the day. Indeed, as a general rule, the highest concentrations of BOD_5 tend to coincide with the highest flow rates. Thus, the constant flow rate to the WRAP system does not constitute a good composite sample of the effluent from the primary sedimentation basin. Rather, it is strongly biased in favor of the low flow, low concentration condition that occurs in the late evening and early morning hours. A true composite sample of the primary effluent would be likely to contain a BOD_5 concentration around 20 to 30 percent greater than the concentrations shown in Table 1. It is not apparent, however, that a variation in the time rate of adding waste to the system would have any effect on its efficiency as long as the daily waste load added remained more or less constant.

CONCLUSIONS

Subject to the operating conditions, loading rates, and weather conditions that prevailed during the period in which the pilot plant was monitored, the following conclusions can be drawn:

1. The WRAP system as operated produces a very high quality effluent.
2. In most respects, the effluent produced is not substantially different in quality from the tap water available in the city. In terms of hardness, it is much better than tap water.
3. No conclusions can be drawn regarding the maximum loading rate to which the system may be subjected without causing adverse

effects on the quality of the effluent.

4. There is no reason to believe that a larger system would not produce equally satisfactory results when subjected to similar loading conditions, although short-circuiting can become troublesome if care is not taken in the design of much larger systems.
5. The effluent produced by the system should be usable for a wide variety of industrial purposes. Indeed, it appears that it would be superior to City of Lubbock tap water for use as cooling water because of its low hardness.
6. Finally, an observation not supported by data obtained in this monitoring program is that, for aesthetic purposes, it appears that it would be highly desirable that a skimmer be installed ahead of the WRAP system to remove all floating materials from raw sewage before introducing it to the system.



PRELIMINARY REPORT
FOR A
1.2 MILLION CFD
METHANE GAS PLANT

LOCATED IN
DEAF SMITH COUNTY, TEXAS

FOR
SOUTHWEST MORTGAGE COMPANY

DALLAS, TEXAS

E R A , I N C . ■ ENGINEERS—CONTRACTORS ■ L U B B O C K , T E X A S

Preliminary Report for A 1.2 Million CF/Day Substitute Natural Gas

(SNG) Plant for Southwest Mortgage Company, Dallas, Texas to be

Located in Deaf Smith County, Texas

Description of Project

(a) Introduction

The energy "crisis" is being felt world-wide. Our nation is feeling the full impact of the problem for the first time. Conservation measures are essential in minimizing the shortage. Expansion of the production of fossil fuels will also help. Technology to increase the use of coal (such as gasification, desulfurization, etc.) will also be an important response. However, there is an urgent need to deter the consumption of nonreplacable fossil fuels merely for the production of energy. There are optional sources of energy that are non-depleting and development of these sources is mandatory if civilization is to continue indefinitely on a high energy diet.

This proposal considers the most logical option: That of turning a liability and a resource waste into energy, an asset, and a resource producer. None of the other options such as solar, geothermal or wind energy can make such a contribution. In addition, none of the other options have such extensive history, technical background or operating experience that would allow such rapid large-scale application.

The 1.2 Million cubic foot per day plant, herein described is only one step forward in the solution of the nations energy shortage. Nationally the production of manure is over 2,000,000 tons annually. If the dry solids content of this manure is estimated at 20% and a net production

of 8560 cubic feet of methane per ton is assumed, the total annual methane production from this source could amount to over 3.4 trillion cubic feet. This quantity plus a potential of 1.7 trillion from municipal solid wastes is equal to approximately one-fourth of the present annual natural gas consumption.

In addition to the gas, digested sludge is taking on increased potential value as the energy crisis deepens. A shortage of energy is producing a shortage in manufactured fertilizer (primarily ammonia) and manufactured protein (primarily urea). By converting the noxious manure to an inoffensive humus material with much value as a soil conditioner and possible feed value, the system could become quite lucrative. Value of the sludge as a soil conditioner is upwards of \$50 per ton bulk, FOB plant site.

The marketability of the products from the SNG Plant has been established. The Natural Gas Pipeline Company of America has a trans-continental pipeline adjacent to the East and South side of the tract of land, on which ERA, Inc. proposes to construct this facility. This tract is also adjacent to the P&SF RR Co. R.O.W.. This transportation company has been most cooperative with ERA, Inc.. Should it be more profitable to ship the residue from the plantsite, the P&SF RR Co. would like to negotiate the handling of this material. The residue of sludge from the facility will be used as a high protein feed supplement by the feedlots, or marketed as a soil conditioner and fertilizer. This market is very strong at the present time. The shortage of commercial fertilizer for the farming industry makes the residue from our SNG Plant very much in demand for the lawn and garden industry.



Process Flow Pattern

(1) Manure is fed into the blender and mixed with water and thickened seed to the proper consistency. (2) Diluted, seeded manure is continuously fed into Stage 1 Digester which is continuously mixed and pressurized through standpipe common to Stage 1 and Stage 2. (3) From Stage 1 sludge flows into Stage 2 which is also continuously mixed. Sludge is also continuously recirculated from Stage 2 through an external heater into Stage 1. (4) Sludge is continuously withdrawn from Stage 2 and thickened. Approximately one-half of the thickened sludge is recirculated as seed into the blender; the remainder is applied to drying beds prior to final drying and sale. (5) Methane gas is withdrawn from the digester domes and compressed.

Proprietary Methods of High-purity Methane Production

The methane content of gas produced by anaerobic digestion varies with the composition and concentration of the substrata in which the digestion occurs. Other factors also have a bearing upon the purity of methane produced. ERA has a proprietary method of producing methane of high purity from anaerobic digestion. Commercial scale evaluation of this method will be afforded by this initial commercial plant. The ERA technology will also increase methane production as well as purity. This method of digestion will greatly improve the economics of methane production by obviating the need for scrubbing of the acid gas which normally accompanies methane production. As soon as the operating characteristics of the initial plant are satisfactorily evaluated, construction of additional commercial units can commence. Contracts for sludge and gas are readily forthcoming and relief for the energy crisis can be achieved without additional government funding in this area.



Hereford Operation Plan

The Hereford plant configuration is indicated in Figure 3. Dry feedlot waste will initially be processed through a hammermill, diluted with a combination of sewage water and recycled oxidation pond water and mixed with thickened recycled sludge in the dilution tank. From the tank, the diluted material will be fed into the first stage (primary) digester for approximately five days detention; then into a second stage digester for five additional days. Sludge will be fed and withdrawn continuously to provide a efficient, smooth operation. From the digesters, sludge will be processed through a thickener. A thickener gives two distinct advantages: (1) It will produce a sludge of maximum solids content which is still fluid and (2) it produces a sludge which dewateres very rapidly.

A portion of the thickened sludge will be recycled to the dilution tank. The remainder will be applied to stabilized dewatering beds. The underflow water from the thickener, plus any run-off from the dewatering beds, will enter an oxidation pond. Ammonia appears to be the limiting factor in water recycle and reuse in such a system. Experience has shown that ammonia reductions in excess of 75 percent are readily achieved in oxidation ponds. In this way, 75 percent of water requirements may be met by recycling. Wastewater produced by this process would be approximately 320 gallons per minute.

The sludge residue will then be available after being dewatered to 35 to 40 percent moisture for final drying and packaging for marketing.

Data Collection

The basic technology of anaerobic digestion is well founded upon extensive experience in the operation of municipal waste treatment plants. Results

have been obtained by various researchers on other organic materials, including beef cattle wastes, on small scale tests. What needs to be determined, is precise engineering data upon which to base future commercial methane production facilities.

A significant amount of analytical work including TOC, bacterial counts, volatile acids, alkalinity, pH, sodium, ammonia, total solids and total volatile solids will be required for digestion control studies. Methane, carbon dioxide and hydrogen sulfide measurements will be made for volume and quality of gas production. Organic nitrogen, phosphorous, potassium and volatile solids will be monitored on the digested sludge for potential soil conditioning and feed values. Various solids and liquids retention times will be evaluated for relative efficiency.

(1) Optimum moisture level- There is a range of moisture content within which digestion efficiency is greatest. Based upon experience by other researchers on bench scale beef cattle waste tests, the upper limits may be as much as 15% solids content. Other consideration in addition to efficiency of digestion include handling ease, heat transfer, and water consumption.

(2) Water recirculation rate- Ideally anaerobic digestion must be carried out using recycle of sludge to obtain long solids retention times (i.e. 10 days) and liquid times of only 12 hours. This operating regime is possible, providing the accumulation of inhibiting ions such as ammonium or sodium do not become excessive. If build-up on such ions is excessive, recirculation rates on water will have to be reduced. This will mean that larger quantities of fresh water will be consumed by the operation and larger quantities of wastewater will be produced.



(3) Digested sludge characteristics- The nitrogen content of digested sludge may vary considerably. Higher nitrogen content enhances the potential value of sludge as a by-product, either for use as a soil conditioner or as a protein feed supplement. Feedlot wastes from beef cattle normally run somewhat higher in nitrogen content than manure from such sources as dairy cattle or sheep. This is primarily due to the high protein level of rations feedlots. As a result, digested beef manure sludges will run high in nitrogen and with recirculation of ammonia-bearing water (below the toxicity level, of course), a final sludge with a nitrogen content in excess of 5% should be possible. Anthony at Auburn University has produced sludges with 7% nitrogen by introducing ammonia to the fermentation process. The production of sludge with economic value can greatly improve process economics.



**Production Factors
For a High Plains Methane Project**

<u>Manure Values Dry Basis</u>	<u>Gross</u>	<u>Net</u>
Per Head per Day (Pounds) Dry Weight	9.2	--
Volatile Solids (Percent)	80	--
Methane per Pound Volatile Solids (Cu. ft.)	6.00	5.35
Methane per Ton Dry Manure (Cu. ft.)	9600	8560
Methane per Head per Day (Cu. ft.)	44.1	39.3
Service Base for One Million CFD (Hd)	22,700	25,400
Daily Tonnage (dry) for One Million CFD	104	117

Internal fuel expense for heating of digesters and new sludge is projected at 12%. The per head figure is based upon EPA estimates as is the volatile solids content. Methane production is conservatively based upon data from Loehr.²⁷

Projected Gas Composition

Methane - 98% Minimum

Carbon Dioxide - 2% Maximum



Area to be Served

Hereford, Texas, the county seat of Deaf Smith County, is located in the southern panhandle of Texas. At an elevation of approximately 3780 feet above sea level, it is located on U. S. Highway 60 approximately 50 miles from Clovis, New Mexico and Amarillo, Texas.

Deaf Smith County, and the area surrounding Hereford particularly, has many cattle feeding operations. In 1973 the county had a total daily feedlot capacity of approximately 300,000 head. Four lots with approximately 125,000 head capacity are located just east of the city of Hereford. The close proximity of these four feedyards lends itself to a cooperative effort on their part. The proposed SNG facility will utilize only 25% of the capacity of these four feedlots. Taking advantage of the total feedlot potential, in the Hereford area, an expansion of ten-fold would be accomplished. Figure No. 1 shows the locations of these four feedyards.

Deaf Smith County, as well as a large area of the Texas Panhandle, the Panhandle of Oklahoma, and a portion of Southeastern New Mexico is served with electricity from Southwestern Public Service Company. This company has its corporate offices in Amarillo and has devoted much time and effort toward compiling data relative to the cattle feeding industry in their service area. Figure No. 2 shows the total feedlot capacity in this area.

Cost Analysis

The following preliminary bid items together with the projected cost of each is representative of the proposed SNG Plant for the Hereford area. These costs have been derived from consultation with companies which have had many years experience in their field.

Financing of Project

All necessary arrangements have been made between Southwest Mortgage Company, Two Turtle Creek Village, Dallas, Texas and ERA, Incorporated for the construction of the proposed facility. The SNG plant will be constructed by the Southwest Mortgage Company and then leased to ERA, Inc. for operation and maintenance. All income from the SNG plant will originally go to ERA, Inc.. Out of this income ERA will pay the amortization, operation, maintenance, and marketing of the final products.

The funding of the proposed plant is contingent upon obtaining a guarantee of the lease payments from the FmHA. This agency has indicated a commitment is forthcoming. Financing of SNG plants through this method will alleviate the expenditure of federal funds for the solution of a portion of the energy shortage.

Environmental Impact

The construction of the proposed SNG plant will not adversely effect the environment at this location. The structure will be enclosed and pressurized thereby preventing the escape of any odors or noxious gases. Any odor problem will be in the stockpile of manure. Due to the proximity of existing feedlots, this will not change the existing condition.

The amount of CO₂ exhausted from the SNG plant will not be sufficient to cause any environmental problems. The height of the exhaust stack will allow the exhausted CO₂ to dissepate before reaching ground level. For comparative purposes, the amount of CO₂ from the exhaust stack of a power generating plant, is considerably greater then that from the proposed SNG plant.



All waste water will be held in an evaporation pond. There will be no discharge into any stream.

Recommendations and Conclusions

It seems that the United States of America is now confronted with many problems in the fields of production of energy, water pollution, etc.. These problems have been brought about through neglect on the part of those in power to recognize the fact that there could be a shortage of energy from natural sources, and that our water resources are exhaustible also.

The technology exists to solve a large portion of these problems. It is ERA, Inc.'s position, instead of letting federal agencies try to solve these problems, that private industry can do the job much more efficiently. Instead of providing funds from tax dollars, why not let the private sector solve these problems for one-half the projected cost. The inefficiency of bureaucratic control of the nations problems has been well documented.

It is recommended that this project be approved as outlined above and that one aspect to the energy crisis be resolved without federal intervention.

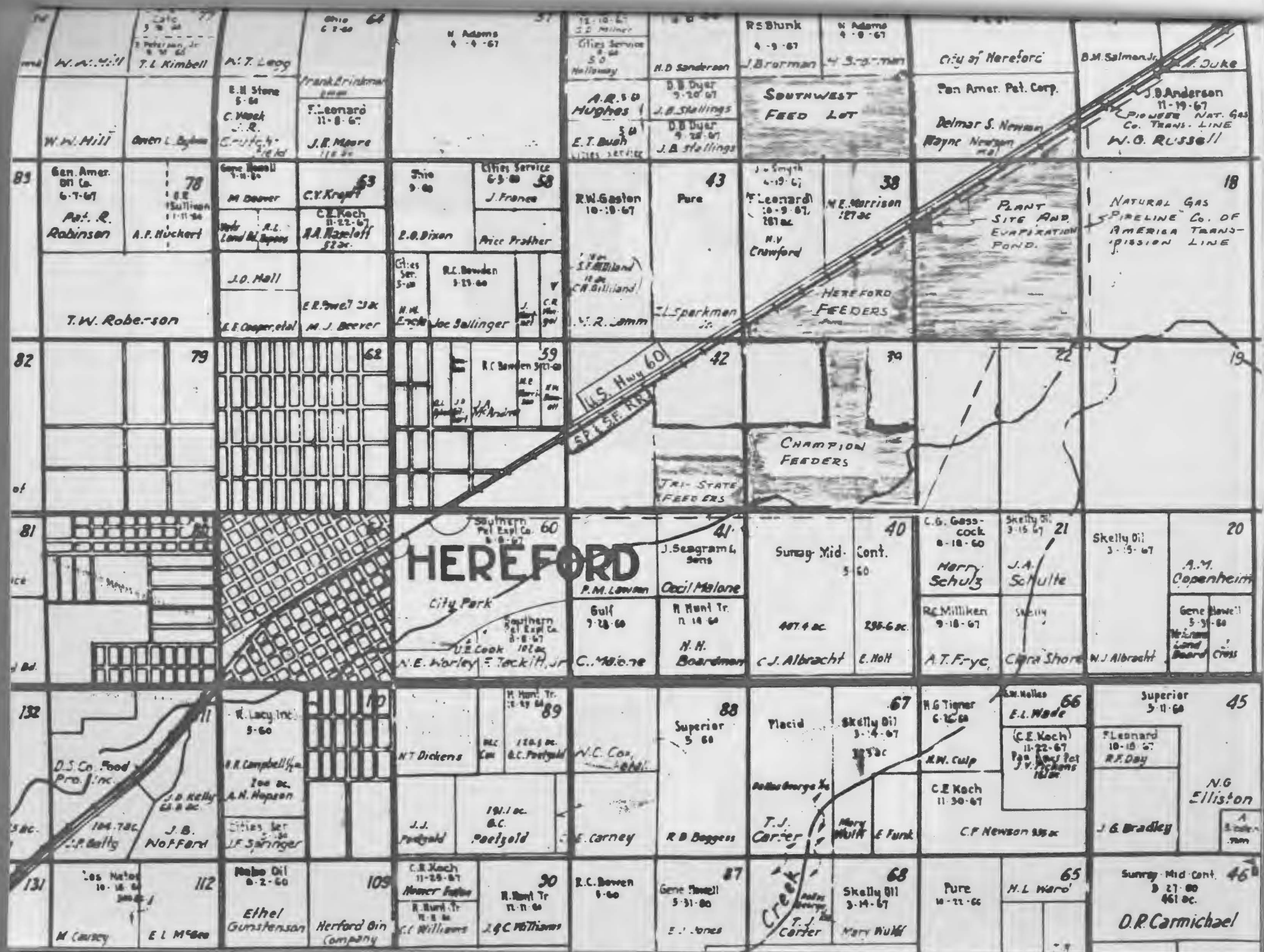


FIGURE 2

FED CATTLE INDUSTRY

1973 REPORT

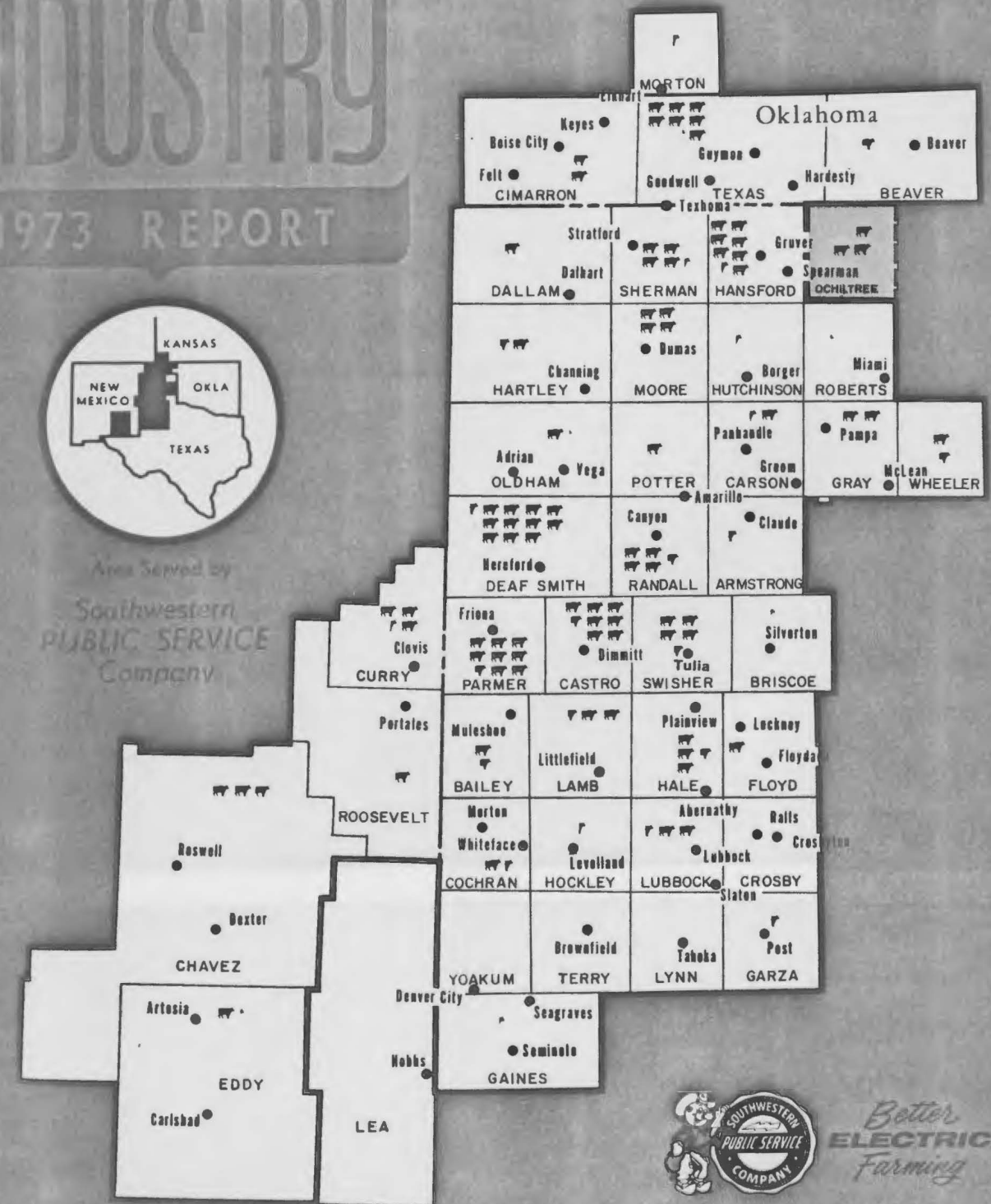
Fed Cattle Production
In Company Service Area

4,679,098 HEAD

☐ = 50,000



Area Served by
**Southwestern
PUBLIC SERVICE
Company**



*Better
ELECTRIC
Farming*

AGRICULTURAL DEVELOPMENT DEPARTMENT

SAM A. THOMAS
Agricultural Development Manager
Box 1261
Amarillo, Texas 79105

GLENN D. BICKEL
Agricultural Consultant
Box 681
Lubbock, Texas 79406

ROY FLOOD
Agricultural Specialist
Box 1937
Roswell, New Mexico 88201

MARCH, 1973

PACKING PLANTS - 1973

Total Average Annual Capacity
3,474,000

NAME	MAP LOCATION NO.
SWIFT & COMPANY Guyman, Oklahoma	1
AMERICAN BEEF PACKERS, INC.* Cactus, Texas	2
WESTERN BEEF PACKERS, INC. Pampa, Texas	3
AMARILLO PACKING COMPANY Amarillo, Texas	4
GLOVER PACKING COMPANY Amarillo, Texas	5
WEST TEXAS DRESSED BEEF CO., INC.* Amarillo, Texas	6
CAVINESS Hereford, Texas	7
ARMOUR & COMPANY Hereford, Texas	8
MISSOURI BEEF PACKERS, INC. Ft. Worth, Texas	9
SWIFT & COMPANY Clovis, New Mexico	10
MISSOURI BEEF PACKERS, INC. Plainview, Texas	11
FARM PAC KITCHENS Lubbock, Texas	12
JOHN MORRELL & COMPANY Lubbock, Texas	13
GLOVER PACKING COMPANY Roswell, New Mexico	14
CAVINESS Dalhart, Texas	15
HATCH PACKING COMPANY Portales, New Mexico	16

*Under Construction

CATTLE FEEDLOTS

COUNTY	NAME	SIZE	SITE NO.	COUNTY	NAME	SIZE	SITE NO.
Cherokee, OK	Boles City Feed Yard	8,000	1	Farmer, TX	Latina Feedlot, Inc.	10,000	56
	Crutcher Feeders, LTD	18,000	2		Cattaloon, Inc.	10,000	57
	Felt Feeders	7,000	3		Far Tex Feedlot	8,000	58
	SGT Feedlot	12,500	4		Flona Feed Yard, Inc.	10,000	59
Terrell, OK	Grounds Feed Yard	1,000	5		Hi-Plane Feed Yard	51,000	60
	Hitch, H. C. Feedlot	20,000	6		Pace Feed Yard	17,000	61
	Jellis, Worth	5,000	7		Palmer County Cattle Co.	17,000	62
	Master Feeders	40,000	8	Castro, TX	Clanton Feed Yard	12,000	63
	McKinney Feed Yard	10,000	9		Chisel Cattle Company	17,500	64
	Pride Feeders	15,000	10		Dingwall Feedlot	42,000	65
	Schner Beef	25,000	11		Hall Feeders, Inc.	10,000	66
	Texas County Feed Yard	27,500	12		Hill Feed	7,500	67
	Glen Trim Feed Yard	5,000	13		Hill Feedlot	25,000	68
Beaver, OK	Panhandle Feed Yard	15,000	14		Kemp & Kemp Feedlot	7,500	69
Dallam, TX	Bar D Feedlot	10,000	15		Pro Feeders, Inc.	23,000	70
	Nortex Feedlot	16,000	16		Sunnyvale Cattle Company	13,000	71
	Yerlins Feed Yard	8,000	17		Taylor Feedlot	8,000	72
Sherman, TX	Cluck, Dean	11,000	18		United Beef Producers, Inc.	13,000	73
	Freeman Feedlot, Inc.	7,000	19	Swisher, TX	Prairie Cattle Company	12,000	74
	Walter Lerley & Sons	10,000	20		Swisher County Cattle Co.	60,000	75
	Stratford Feed Yard, Inc.	60,000	21		Tulia Feedlot, Inc.	27,000	76
Hansford, TX	Caprock Feed Yard	30,000	22	Belley, TX	Belley County Feeders	6,200	77
	DGC Feeders	10,000	23		Chow-Tex Feedlot, Inc.	15,000	78
	F.M.W. Feed Yard	35,000	24		King Feedlot	17,000	79
	Frontier Feeders	32,000	25	Lamb, TX	Olsen Feed Yard, Inc.	29,000	80
	Hansford Feed Yard	50,000	26		Sudan Livestock & Feeding	18,500	81
	Harvey, T.C.	5,500	27	Hale, TX	Carter-Kirchoff	24,000	82
	Palo Duro Feeders	12,500	28		HCK Cattle Company	7,500	83
Hartley, TX	Dalhart Feed Yard, Inc.	50,000	29		PGC-South Plains Division	35,000	84
	XIT Feed Yard	30,000	30		J. C. Rhoderick & Sons	10,000	85
Moore, TX	Cactus Feeders, Inc.	42,000	31		Shepard Feedlot	12,000	86
	Dumas Cattle Feeders	25,000	32	Floyd, TX	Lockney Feed Yard	25,500	87
	Texas Beef Producers	22,000	33	Cochran, TX	Owens Feed Yard	40,000	88
Hutchinson, TX	McCley, Wilson	6,000	34	Hockley, TX	Anderson-Slaggs	12,000	89
Oldham, TX	Meta Verde Feed Yard	30,000	35	Lubbock, TX	Afford Feedlot	5,000	90
Polier, TX	PGC-West Plains Division	14,000	36		Caprock Cattle Company	5,000	91
Carson, TX	Bond Cattle Company	8,000	37		Lubbock Feedlot, Inc.	45,000	92
	Carson County Feeders, Inc.	15,000	38		Three "C" Cattle Co.	10,000	93
Gray, TX	Cockrell Cattle Company	20,000	39	Gaines, TX	Gaines County Feeders	15,000	94
	Heaton Cattle, Inc.	25,000	40	Curry, NM	Bogle & Bogle, Inc.	8,000	95
	Moody Farms	18,000	41		Castor Feed Pens	15,300	96
Wheeler, TX	Beef Cattle Company	30,000	42		Clovis Feedlot	10,000	97
	Prime Feeders, Inc.	15,000	43		Texico Feedlot	7,000	98
Deaf Smith, TX	Big-Tex Cattle & Grain	32,000	44		Waldhauser, Ted	5,000	99
	Champion Feeders, Inc.	36,000	45		Worley Feed Pens	25,000	100
	Deaf Smith Feed Yard	35,000	46	Roosevelt, NM	Anderson-Slaggs	13,000	101
	Hereford Feed Yard	51,000	47		Better Beef, Inc.	10,000	102
	Pitman Feed Yard-East	25,000	48	Chaves, NM	Barnett Feed Yard	25,000	103
	Pitman Feed Yard-West	35,000	49		Bogle Farms, Inc.	15,000	104
	Southwest Feed Yard	42,000	50		Chaves County Cattle Corp.	17,000	105
	Sugarland Feed Yard	25,000	51		Hershey Feedlot	15,000	106
	Texon Feed Yard, Inc.	15,000	52		Langenegger, Bill W.	15,000	107
Randall, TX	Happy Wheat Growers, Inc.	25,000	53		Linkford, Royce	8,000	108
	Randall County Feed Yard	81,000	54		Watson, Albert	6,000	109
Armstrong, TX	Parker Cattle Company	5,000	55	Eddy, NM	Seven Rivers Cattle Company	20,000	110

PACKING PLANT LOCATIONS



Packing Plant
Locations



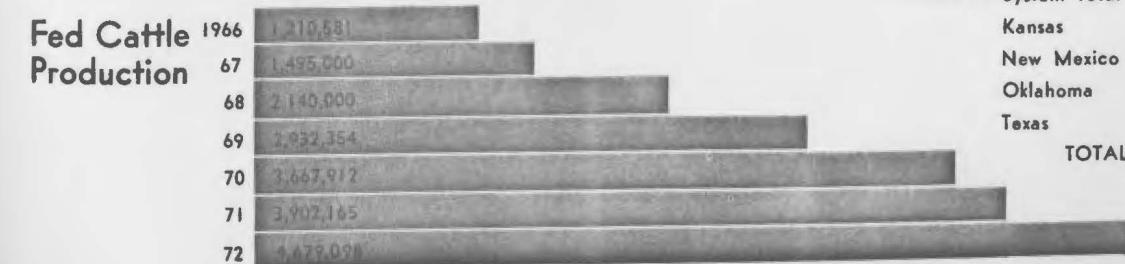
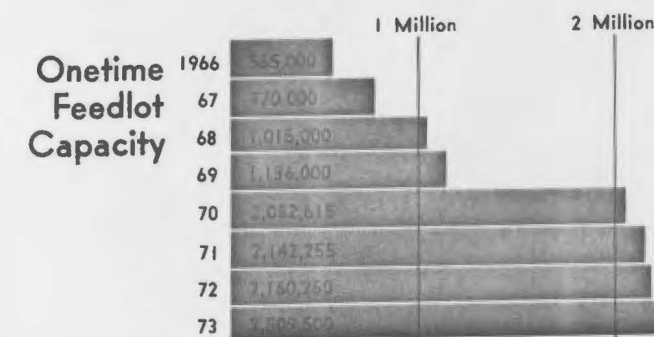
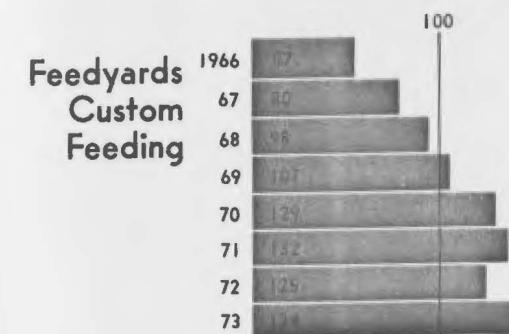
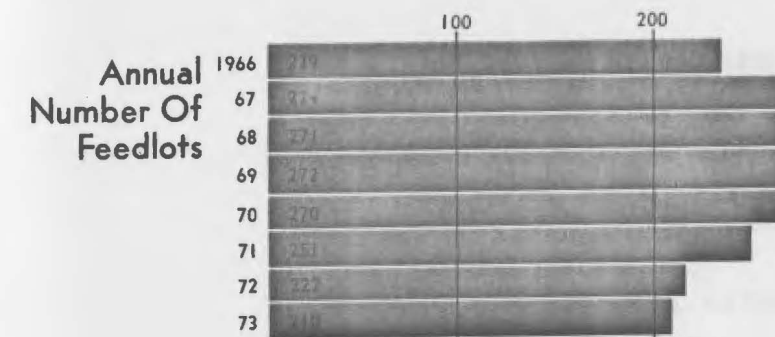
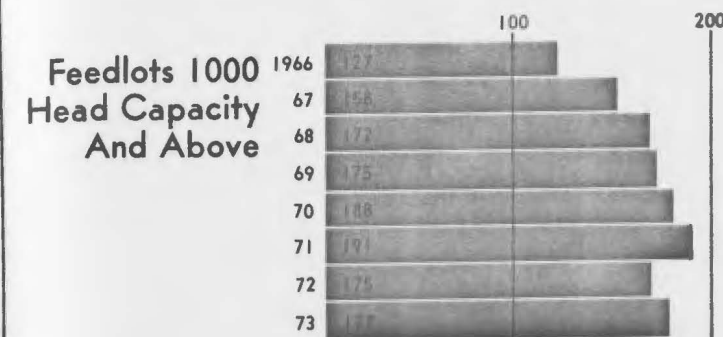
FEED LOT LOCATIONS

Feed Lot Locations
5,000 Capacity
and Over



*Better
ELECTRIC
Farming*

1973 FED CATTLE REPORT IN COUNTIES WITH SOUTHWESTERN PUBLIC SERVICE COMPANY SERVICE
TEXAS - NEW MEXICO - OKLAHOMA - KANSAS



STATE & COUNTY	Lot Capacity Now	No. Fed in 1972
KANSAS		
Morton	15,650	15,550
NEW MEXICO		
Chaves	112,100	140,868
Curry	76,800	163,100
Eddy	21,800	55,780
Roosevelt	29,200	44,600
TOTAL	239,900	404,348
OKLAHOMA		
Beaver	21,300	40,350
Cimarron	45,500	94,964
Texas	164,850	356,160
TOTAL	231,650	491,474
TEXAS		
Armstrong	10,600	22,780
Bailey	41,200	76,000
Briscoe	1,200	1,125
Carson	26,000	63,500
Castro	205,300	379,400
Cochran	40,000	68,000
Crosby	NONE	REPORTED
Dallam	36,200	45,100
Deaf Smith	297,200	574,108
Floyd	30,600	50,900
Gaines	16,200	3,700
Garza	2,500	7,500
Gray	63,000	93,634
Hale	94,100	186,300
Hansford	180,700	366,895
Hartley	83,500	83,000
Hockley	18,000	16,500
Hutchinson	6,000	6,500
Lamb	56,500	129,850
Lubbock	65,000	122,500
Moore	92,000	206,000
Oldham	31,200	57,774
Parmer	230,100	428,900
Potter	18,500	38,350
Randall	113,600	228,050
Roberts	3,000	1,000
Sherman	96,100	208,360
Swisher	119,000	222,000
Wheeler	45,000	80,000
TOTAL	2,022,300	3,767,726
System Total		
Kansas	15,650	15,550
New Mexico	239,900	404,348
Oklahoma	231,650	491,474
Texas	2,022,300	3,767,726
TOTAL	2,509,500	4,679,098

FOR A

SYNTHETIC NATURAL GAS PLANT

AT HEREFORD, TEXAS

FOR: SOUTHWEST MORTGAGE CO.
ERA., INC.

RICHARD P. CHENEY & ASSOCIATES
ENGINEERS

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Gravel and Crushed Stone	XXVII
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Gravel and Crushed Stone	XXIX
Gravel and Crushed Stone	XXX

SECTION I

- A. Standard notice to contractors of intent to construct facilities.
- B. Bid form outlining item to be bid whether by lump sum or by item.
- C. Standard form of agreement between owners and contractors.

SECTION II

General Conditions of Agreement: The general conditions will specify the responsibilities of the owner, contractor and engineer.

SECTION III

- A. Site Preparation: The area shall be cleared of foreign and natural matter and brought to finish elevations. Back fill if necessary shall be performed in a workman like manner and shall be compacted to densities as specified.
- B. Paving: The areas shown shall be paved with 6 inches of base material and 1½ inches of hot mix material as specified.

SECTION IV

Concrete: All concrete used shall be class "A" 3000 psi concrete with a minimum of 5½ sacks of cement per cubic yard. Aggregates shall conform to applicable ASTM specifications. Adequate sampling shall be performed to insure compliance with specifications.

SECTION V

Dry Material Feed System: Dry material shall be batch dumped into a pit equipped with an auger and bucket elevator system. The elevator system shall discharge into a grinder as specified in Section VI. The grinder will be capable of discharging to a storage bin capable of discharging a continuous feed of 234 lbs/min. to the blending apparatus. The blender shall be as specified in Section VII.

SECTION VI

Grinder: The grinder shall be of the size and capacity shown and shall be a W-W Model F-22M as manufactured by the W-W Grinder Corporation.



SECTION VII

Blending System: The blending system shall be of the size and capacity indicated on the plans and shall be as manufactured by the Gruendler Crusher and Pulverizer Co. of St. Louis, Missouri.

SECTION VIII

Grit Chamber: The grit chamber shall be of the size indicated on the plans and shall be capable of removing a maximum amount of sand and grit without removing organic materials. The chamber shall be a Rex Gritreat Chamber as manufactured by Rex Chainbelt, Inc. of Milwaukee, Wisconsin.

SECTION IX

Digesters: Digesters shall be of 500,000 gallon capacity each. D-1 Digesters shall be welded steel capable of operating at 38 psig head pressure. D-2 Digesters shall be welded steel capable of operating at 38 psig head pressure. All design and construction shall conform to the current ASME Specifications for Unfired Pressure Vessels.

SECTION X

Gas Mixing System: A gas mixing system shall be installed to maintain a homogeneous mix in the digester. The system shall be a PFT-Pearth Gas Recirculation System as manufactured by Rex-Pacific Flush Tank Company or approved equal.

SECTION XI

Water De-Gas System: The Water De-Gas System shall be of the size and capacity shown and shall be as manufactured by Westinghouse - Infilco Company. The de-gas system shall be a Westinghouse - Infilco Multicone Aerator of the induction cascade type.

SECTION XII

Heating System: Heaters to be installed as indicated and shall have a sludge heating capacity of 250,000 BTU/hr and a boiler output rating of 260,000 BTU/hr heaters shall be as manufactured by PFT Division of Rex Chainbelt, Inc.

SECTION XIII

Flotation: Flotation units shall be installed as shown and shall be Flot tazur Separators as manufactured by The Gulf Degreemont Company.

SECTION XIV

Gas Stripping and Compression: Equipment shall be provided to strip the gas stream of CO_2 , H_2S , and H_2O to provide gas line quality gas. The stripping and compression shall be as manufactured by BS&B Company of Houston, Texas.

SECTION XV

Flash Dryer: A flash dryer capable of moisture removal and reduction of material to a fine, dry, uniform, finished product shall be installed. The dryer shall be as manufactured by the Raymond Division of Combustion Engineering.

SECTION XVI

Pumps: Pumps shall be of the non-clog type of the sizes shown and shall be installed as indicated.

SECTION XVII

Pipe: Pipe shall be steel pressure pipe of the size and class as indicated on the plans. The pipe and installation shall conform to applicable AWWA, ASTM and ASME Specifications.

SECTION XVIII

Valves: In general valves shall be of the size indicated and shall be of the size indicated and shall be of the screwed gland type or other non-clog type valve and shall be motorized in the locations indicated.



SECTION XIX

Flow Metering: Flow meters to monitor water flow shall be installed in the locations as indicated and shall be of the non-clog variety capable of monitoring flow in gallons per minute and compled to a totalizer for long term monitoring.

SECTION XX

Gas Metering: Gas meters shall be provided for metering flow from each digester and for metering total flow from the plant. A meter shall also be provided to meter in-plant usage.

SECTION XXI

Electrical: The electrical system shall be installed as shown to provide adequate service. Materials shall be manufactured and installed in compliance with applicable AIEE, NEMA, and local codes.

SECTION XXII

Controls: Controls shall be provided to automate all phases of operation. The system shall have a central control panel and shall be as manufactured by the Auto-Con Company or approved equal.

SECTION XXIII

Monitoring Devices: Automatic monitoring devices shall be installed to automatically monitor critical phases of operation. These will include but not be limited to the following: Ph, Temperature, CO₂ Concentration, Pressure and Sodium Concentration.

SECTION XXIV

Lagoons: Lagoons shall be constructed as shown. Earthwork for lagoons shall be in conformance with Section III of these specifications. Concrete shall be in conformance with Section IV.

SECTION XXV

Building: The building shall be of frame and stucco construction as shown and shall conform to local and state codes.

BID ITEMS BY SECTION

3. Site Grading & Paving	\$ 30,000.00
4. Concrete	80,000.00
5. Feed System	20,000.00
6. Grinder	12,000.00
7. Blending System	10,000.00
8. Grit Chamber	35,000.00
9. Digesters	900,000.00
10. Gas Mixing	40,000.00
11. H ₂ O Degas	30,000.00
12. Heating	150,000.00
13. Flotation	70,000.00
14. Stripping and Compression	140,000.00
15. Flash Drying	65,000.00
16. Pumps	55,000.00
17. Pipe	80,000.00
18. Valves Manual Motorized	30,000.00 36,000.00
19. Flow Meters (Water)	12,000.00
20. Flow Meters (Gas)	10,000.00
21. Electrical	40,000.00
22. Controls	60,000.00
23. Monitoring Devices	25,000.00
24. Lagoons	16,000.00
25. Building	12,000.00
	\$1,958,000.00

