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Project Summary

Optimization of Wastes Treatment with Reference to Biogas and Protein Recovery

Jan A. Oleszkiewicz and Szymon Koziarski

Detailed technological and economic evaluations of the presently used treatment processes for the dilute wastewaters from hog farms, with capacity exceeding ten thousand head, is presented. The present systems of treatment for stfeam disposal encompass sophisticated multi-stage chemical-biological treatment with high unit cost due to consumption of power, oil, and chemicals.

The intent of the research part of the project was the optimization of the unit process and whole treatment trains selection, rather than unit process operational parameters. The unit processes investigated in the laboratory and pilot scale included: sedimentation, coagulation, activated sludge as a roughing unit and as a polishing unit, algal-bacterial (oxidation) polishing ponds, anaerobic digestion in flow-through and contact reactors with suspended microorganisms and in anaerobic biofilters, anaerobic ponds, aerated lagoons, and yeast generation, as a method of treatment and protein recovery.

The results indicate the need for diametrical shift in research emphasis in animal wastes, towards high-rate, short detention time anaerobic unit process combined with high-rate aerobic secondary treatment and anaerobic-aerobic polishing treatment. Several full technological treatment trains were evaluated and compared from the standpoint of treatment efficiency, level of recovery, ease of maintenance and economic efficiency indices. The systems recommended were comprised of anaerobic biofiltration or contact digestion followed by anaerobic biofiltration, anaerobic biofiltration and reaeration, with anaerobic sludge digestion as a separate sludge train or incorporated in the wastewater treatment train. Economic analysis has shown that the application of these new treatment trains can make industrial-scale farming more profitable with the increase in the size of the farm. This is contrary to the presently observed trend toward limiting the construction of large farms, due to the environmental constraints. The prevailing trend stems from the application of either conventional wastewater treatment technology to these concentrated effluents or application of agricultural utilization practices as used for concentrated manures from smaller farms.

The technology proposed in the project shows an increase of the economic efficiency, when compared to conventional systems. The new technology incorporates biogas recovery and a sludge treatment subsystem in the overall treatment-recovery train. Although the report is confined to swine wastes, the results are applicable to other concentrated effluents from the agricultural industry.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Project Aim

The shortage of litter and the growing demand for animal protein have caused several countries to turn to industrial-scale animal production. Large hog production plants in central Europe usually house from 10 to 40 thousand animals. In several instances, larger farms were built, notably in Romania and the USSR, where the size may approach 250 thousand hogs. The magnitude of operational problems and the environmental requirements associated with these enterprises can be realized by taking into account the fact that a 36.5 thousand hog farm will require annually over 1.9 x 10^8 watthours of power, up to 18 x 10^6 kg of fodder and close to 3.2 x $10^5 m^3$ of water.

Figure 1. (A) illustrates the hog production trends in two countries, Holland and Poland. Figure 1. (B) shows the increase of industrial-scale hog and cattle production in Poland. It should be noted that industrial-scale farms are responsible for a much larger segment of overall pig production in such countries as the German Democratic Republic (29 percent), Hungary (47 percent), Romania (60 percent), and Bulgaria (65 percent). Due to technical constraints, new farms are frequently sited in areas unfit for land disposal, and the inevitable stream discharge of effluents requires the highest practicable treatment technology.

The overview of foreign practice in piggery wastewater treatment obtained during visits to plants in USA, Italy, Holland, and Scotland, as well as through the literature perusal, revealed the lack of data on treatment of dilute wastewaters. The trends in these countries is to keep the farms small and manure as concentrated as possible through recycle and decreased water consumption. Thus, available information concerns concentrated effluents for which the process economics are different. The project report fully describes and characterizes the full-scale treatment of dilute pig wastes and evaluates the technological, economic, and environmental applicability of the novel alternative wastewater treatment processes featuring biogas production and single-cell protein recovery.

Project Scope

Based on mail surveys, literature data, field trips, and on-site long-term round-the-clock surveys, a summary of the hog production and wastewater treatment trends is presented. Treatment effects are described and the economic efficiency of various practiced unit processes is critically evaluated. Both practiced and promising future polishing treatment processes are discussed. In-depth feasibility studies are presented, leading to the optimization of the operation of current systems treating effluents for stream disposal and novel systems proposed for future use. Finally, a set of proposals is given setting forth the required treatment for stream disposal, for agricultural utilization, or for combined treatment with other effluents. The proposals are based on a comparison of costs, treatment effects, and non-economic factors which are beginning to play an important role in the agricultural industry (e.g. the shortage of qualified manpower, sight and odor nuisance, lack of adequate land for agricultural disposal).

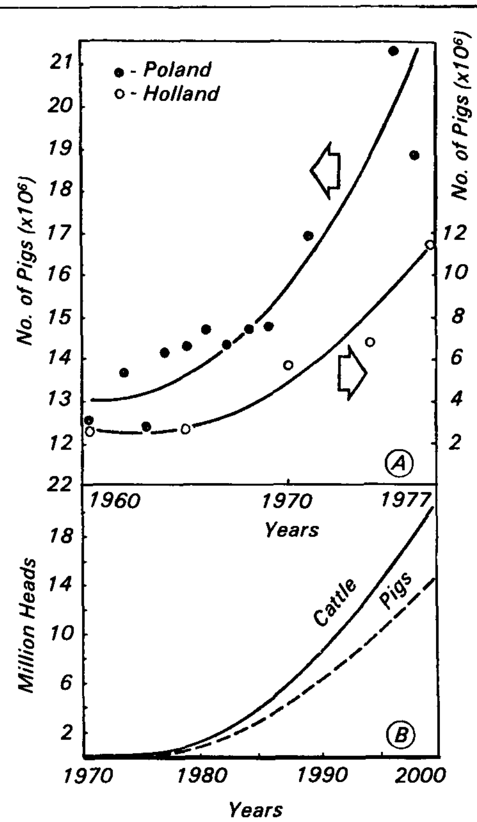

Figure 1. *(A) Overall hog production in two countries; (B) Planned production increase of the industrial farms in Poland.*

Technical Conclusions

The project is aimed at optimizing existing treatment systems for dilute effluents from large piggeries, at optimization of loadings and sequence of unit processes and operations for piggery wastes. The project also places new waste treatment-recovery systems in the proper economic and technological perspective. The project topics could be grouped as follows: a) detailed technological and economic analyses of presently used waste treatment systems (WTS) for dilute wastewaters for several large industrial pig farms; b) an in-depth analysis of results of laboratory- and pilot-scale studies of 14 individual unit processes for treatment of pig wastes; and c) application of results to the design and economic assessment of 12 new complete WTS for two types of large pig farms with partial effluent recycle (i.e. water use 20 dm^3/ hog/day and without recycle, i.e. 28 dm^3/ hog/day).

Operation of today's sophisticated chemical-biological waste treatment system requires close cooperation between farm managers and WTS personnel to keep hydraulic loads within the design limits. Generally, these systems are vulnerable to influent variability, are highly inefficient, and, as costs rise for power, imported chemicals, and oil, are increasingly expensive to operate.

Research in this project shows that piggery waste treatment systems should include a sequence of high-rate processes followed by low-rate low loading processes. Chemical treatment should be replaced by plain sedimentation and/or anaerobic pretreatment. The use of activated sludge should be limited in the high-rate processes class and excluded from the low-rate processes class. Oxidation ponds as a polishing WTS should be used in combination with fish cultivation as a method of biomass harvesting.

The comparison of the various modes of anaerobic digestion shows that dilute piggery waste should be treated in systems having high solids retention time (SRT), low hydraulic retention time (HRT). Gas production and sludge build-up decrease with increasing solids retention time, while the removal ratio and process stability increase. The recovery of gas is economically efficient even at today's power costs, because the anaerobic processes proposed provide large removals of organics.

The recovery of single cell protein (SCP) through aerobic fermentation is found feasible; however, the present costs of protein and nutrients (N and P) make it uneconomical from the standpoint of both the SCP production and waste treatment. Large carbon supplementation is required in order to fully utilize the nutrients contained in piggery wastes.

In all cases, the alternative of combined treatment with other, nutrient lacking, effluents should be investigated because the benefits are usually much higher than the cost of long-distance pressure transport systems.

Long detention time lagoons (anerobic-aerated - oxidation) are a viable WTS, easy to implement and operate in rural conditions. The most efficient WTS, however, includes mesophilic anaerobic biofiltration (ANBIOF) followed by aerobic biofiltration and polishing anaerobic biofiltration. The system utilizes most of the methanogenic potential of wastes by means of a separate anaerobic sludge digestion in an anaerobic flow-through reactor without recycle (ANFLOW) or anaerobic contact reactor with sludge recycle (ANCONT).

The ANBIOF type reactor should always be incorporated in any treatment system as a first or second stage anaerobic digestion, since it significantly improves process stability and allows (as a second stage after an ANCONT reactor) for an increase in organic loading without impairing the gas production or organics removal efficiency.

The major error in disposal of dilute piggery wastes in Europe, up to recent times, was the application of either conventional wastewater treatment technology or the use of manure utilization systems applicable to concentrated wastes. Based on numerous examples of difficulties in disposal of piggery effluents, large industrial farm complexes are now thought to be economically and technologically inefficient. This project has shown that this is not necessarily so, at least from the standpoint of WTS. The accumulation of large organic loadings and relatively low volumes of wastes may be regarded as an advantage in novel, energy efficient, highly reliable gas and nutrient recovery WTS, such as demonstrated in this report.

From the standpoint of the economics of waste treatment, piggeries with capacity smaller than 5,000 head should rely on land disposal. If stream disposal is the final goal, the size of the farm should not have to be limited, since the proposed technology of anaerobic wastewater treatment and sludge disposal improves its efficiency with the increase of farm size. Another factor improving the efficiency of the proposed systems is the decrease of fresh water use through recycle of treated wastewaters.

Outline of the Economic Analysis

Economic optimization of waste treatment/recovery systems is a complex process, which, if done correctly, requires sophisticated mathematical modeling and computer simulation of unit processes performance within the treatment train. However, the effects of the sophisticated approaches (which include presumably all of the foreseeable variables) frequently may not be representative due to an inadequate data base assumption. In the case of animal wastes, most available data are not consistent as to the actual price of biogas, recovered protein, and the costs of comparable unit processes. Due to variations in the technological and constructional know-how of treatment facilities, it is not possible to apply literature data to processes derived in this work.

To summarize the literature search, it is impossible to gain any knowledge of the true economic efficiency of the anaerobic digestion as a waste treatment method, with an additional gas recovery, based on literature data. Similar situations exist in literature on economics of SCP recovery.

The authors decided that a special economic analysis would have to be made in this case of dilute piggery wastes from typical industrial piggery farms. The method of analysis used assumes a ten-year period of amortization of the capital investments. The costs and economic efficiencies of COD removal and of volume of flow removal are based on current 1980 data.

In order to make economic comparisons, several different treatment systems were synthesized for two different sized farms (10,500 and 15,000 head) using actual field data. System I is consistent with the now prevailing concept of rural treatment plants consisting of earthen basins (anaerobic lagoons, oxidation ponds, and agricultural utilization), which can be built by local agricultural enterprises and that are easy to operate. It should be noted that costs are high for this system because of low treatment system efficiencies. System II is the most complicated from an operational standpoint. System II features an ANFLOW reactor with a ten-day hydraulic retention time followed by a thickener and two-stage activated sludge tanks.

System III is similar to System II in the primary, anaerobic, part of the treatment train. The secondary part of System III is much simpler to operate, has a larger specific biogas production, a high-rate low volume secondary treatment in an aerobic biofilter and an anaerobic polishing biofilter.

System IV features a shorter detention time anaerobic digestion in the ANCONT reactors. Based on our experimental evidence, System IV will have only a slightly lower biogas production rate when compared to System III. System IV offers a much smaller volume of anaerobic digestion and a high removal efficiency making for a more stable operation than the other units.

System V features a setting/thickening tank which feeds clarified wastes through a heat exchange to the anaerobic biofilter, where over 80 percent of the COD is removed. The secondary part of System V consists of two-stage activated sludge system, aerobic biofilter, followed by anaerobic biofilter and a polishing unit. This management allows for sludge treatment in a separate ANFLOW reactor while the low concentration wastewater is treated by the anaerobic biofilter, thereby allowing both systems to operate at optimum conditions.

System VI features anaerobic pretreatment of clarified wastewater for pathogen destruction and odor stabilization followed by three months storage prior to land disposal and agricultural utilization.

In all systems, sludges and/or separated solids are air dried and/or composted and applied to land in some manner. Some is used on land controlled by the pig farms and some is sold or given to private gardeners and farmers. Since larger piggeries are frequently sited close to large municipalities and/or with industrial complexes or areas otherwise unfit for land disposal, the study investigated combining pig wastes with other waste streams for treatment. Three possible treatment combinations are discussed:

1. Production of yeast for feeding to animals using piggery wastes and combining these wastes with industrial yeast plant wastes;
2. Combined anaerobic digestion with municipal sludge for biogas recovery; and
3. Combined treatment with nutrient deficient industrial wastes.

Economic Conclusions

The so-called "natural" treatment systems featuring lagoons, oxidation ponds, earthen structures, and agricultural utilization (land disposal), Systems I and VI, have been proved less economical for the modern, large scale industrial pig farm, which uses water in excess of 20 dm^3/hog/d, than the new systems proposed in this project. These new systems utilize full biogas recovery and anaerobic treatment, System V.

Systems I and VI are, however, still more economical than the presently used chemical-biological systems and some of the anaerobic treatment systems now proposed by various sources.

The high concentration of nutrients in piggery wastes makes these effluents an ideal substrate for combined treatment with high-volume, low-concentration, nutrient-deficient industrial wastes.

Location of pig farms close to municipalities creates an opportunity of combining the separated solids from municipal sewage with pig wastes for a more efficient biogas recovery operation.

The location of pig farms within agricultural complexes creates an opportunity to combine other concentrated effluents for gas recovery, waste heat utilization operations in ANFLOW or ANCONT type digesters.

The report concludes that pig farms should have a capacity much lower than 10,000 head if agricultural utilization is to be practiced. If larger farms are erected or where land disposal is not feasible, the piggery wastes should be treated in combination with other industrial effluents or municipal sewage. Due to the increased size of such combined waste treatment facilities and the concurrent generation of marketable products (biogas and digested sludge or compost), a better quality of operation can be maintained than in local plants. The decrease in capital costs is usually significant (e.g. 20 to 25 percent) despite the frequent need for transporting the wastes to the central treatment plant (CTP) site. The decrease in running costs, even without accounting for the recovered biogas, for the joint treatment facilities may be as large as 20 to 50 percent of the sum of these costs at individual plants.

In all cases, advanced biogas recovery high-rate, treatment systems are more technologically and economically efficient than the present treatment systems and will become the only alternative with the increasing energy shortage.

Recommendations

Existing piggeries should initiate a program of changes in water distribution and sewerage systems to cut down the water use, increase the temperature and concentration of raw wastes, and apply recycle with purified wastewaters for flushing purposes.

Full-scale implementation of the proposed anaerobic treatment systems is needed; the design work is presently being completed. Full-scale polishing oxidation ponds are being constructed. A three-year period of studies should encompass various techniques of biomass growth enhancement in cold conditions such as greenhouses, mixed populations, and recycle. Fish cultivation should be researched as a method of biomass harvesting and biological sludge disposal.

New anaerobic treatment processes such as phase separation and selective organics removal systems might further reduce the volume of anaerobic fermenters. The major trend in animal waste treatment technology should be the further optimization of gas recovery and utilization of waste heat, as the rising power costs will rapidly increase the applicability of anaerobic digestion to concentrated organic effluents.

The work on yeast production should be continued with other types of yeasts such as those that require less of the readily available carbon. Studies on continuous cultures, mixed yeasts populations need to be continued, since further rises in protein prices should yield the process more economical.

Methods of direct refeeding should not be pursued as much as the methods of conversion into high protein feedstuffs. Further studies should be conducted in open rather than in close cycles, i.e. feeding other kinds of animals.

Wide technology transfer and agricultural extension programs are needed in order to show the growers, animal husbandry specialists and the agricultural industry as a whole that animal wastewaters can be treated efficiently at any level of dilution, at any volume and in any location. The new, more sophisticated technology required can be achieved with proper liaison between the producer and the sanitary engineer.

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Jan A. Oleszkiewicz in with Duncan, Lagnese and Assoc., Inc., Pittsburgh, PA 15237 and Szymon Koziarski is with the Research Institute on Environmental Development, Wroclaw, Poland.
***Lynn R. Shuyler** is the EPA Project Officer (see below).*
The complete report, entitled "Optimization of Wastes Treatment with Reference to Biogas and Protein Recovery," (Order No. PB 83-183 020; Cost: $20.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P.P. Box 1198
Ada, OK 74820