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Bioenergy Systems Report

MARCH 1985: INTERNATIONAL CONFERENCE ON BIOGAS TECHNOLOGY

INTRODUCTION

This report is devoted exclusively to the International Conference on the State of the Art of Biogas Technology, Transfer, and Diffusion which was held in Cairo, Egypt, from November 17 to 22, 1984. The meeting was organized jointly by the National Research Center of Egypt, the Academy for Scientific Research and Technology (Egypt), the Bioenergy Systems and Technology Project of the U.S. Agency for International Development, and the U.S. National Academy of Sciences.

The conference was unique in that it focussed primarily on developing country experience with anaerobic digestion and biogas systems. It brought together more than 100 participants engaged in biogas activities in 37 countries. To broaden the opportunities for interchange of information and experience, the AID Bioenergy Project sponsored 35 participants from developing countries. The conference coordinator was Dr. M. M. El Halwagi of the National Research Center. The Report provides a digest of the most important information, opinions, and conclusions derived from the conference papers, oral presentations, and discussions. Some papers and presentations dealt with projects described in earlier Reports in this series. In such cases a brief summary is included in this Report and the reader is referred to the earlier Report for additional information. More detailed coverage has been given to some papers on important topics (i.e., fertilizer benefits and health benefits of digestion systems) on which additional information has been urgently needed.

Part One (pp. 2 to 5) outlines the pattern of biogas activities in each of the developing countries represented at Cairo. Part Two (pp. 5 to 13) reviews information presented at Cairo on the various designs for family-sized and large biogas plants. Part Three (pp. 14 to 17) digests information from the conference on the operation of biogas plants. Information on the use of feedstocks other than animal manures is summarized in Part Four (pp. 18 and 19). The benefits which can be obtained from biogas plants are reviewed in Part Five (pp. 20 to 24). Finally, Part Six (pp. 25 to 28) summarizes opinions expressed at Cairo on the factors which influence the diffusion of biogas systems in developing countries.

The institutions represented by the participants from developing countries are listed following their names in Part One; the institutional affiliations of other participants are given with the first reference in the text to each individual. Each participant's country is indicated following the first use of his or her name in each part of the Report.

The AID Bioenergy Project is also sponsoring a comprehensive special report on "Mechanical and Electrical Power From Biogas in Developing Countries" which will be published in the spring of 1985. Important information for that report was obtained from presentations and interviews during the Cairo conference.

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PART ONE: BIOGAS ACTIVITIES IN DEVELOPING COUNTRIES

The following paragraphs provide an overview of biogas projects and programs in each of the developing countries represented at Cairo and in several other developing countries in which European or U.S. organizations are sponsoring or assisting biogas projects.

1. Middle East and North Africa

Egypt (M. M. El Halwagi, National Research Center; M. N. Alaa El Din, Ministry of Agriculture): There are 50 biogas plants in Egypt. Thirteen have been built by the National Research Center under a biogas technology project funded by the U.S. Agency for International Devleopment through the U.S. National Academy of Sciences. The NRC projects have included modified Indian-type and Chinese-type digesters (p. 6), a heated 50 m^3 tunnel digester (p. 8), extensive research on the health aspects of biogas plants (pp. 22-24) and studies of the use of digester effluent as fertilizer (pp. 20-22). The Ministry of Agriculture has built 35 digesters including 7 Chinese-type and 25 Indian-type plants, a 200 m^3 plant on a large chicken farm, and a 150 m^3 plant utilizing kitchen refuse from an army camp (p. 18). The Ministry's program has been supported by FAO, USAID, and the Ministry. It has also included extensive tests of the use of digester effluent as fertilizer (pp. 20-22). The faculties of agriculture and engineering of Cairo University are building an Integrated Renewable Energy System at Fayum which includes three 15 m^3 digesters (p. 13).

Lebanon and Syria (B. Ghougassian, Middle East Center for Appropriate Technology): MECAT built the sole biogas plant in Lebanon with two 40 liter plastic containers connected to form a Chinese-type displacement digester. A biogas plant was built by MECAT in Syria using two 200 liter barrels as the digester and two more barrels as a floating gasholder; gas production was inhibited by a residue of insecticide in the barrels and and by antibiotics in the chicken droppings used as feedstock.

Morocco (A. Fakihani, Center for Development of Renewable Energies): An evaluation report is expected soon on ten Chinese-type digesters installed by CDER in Marrakech province under a USAID-assisted renewable energy project. Tests have also been conducted with a 6 m^3 Indian-type digester and a plastic bag unit. CDER is studying possible larger-scale biogas projects using poultry manure, slaughterhouse wastes, and urban solid wastes.

Tunisia (M. Brini, Institute of National Agronomy): Only one 10 m^3 biogas plant is now in operation in Tunisia. There is a considerable potential for electricity production in major off-grid areas with biogas produced at sizeable livestock farms.

2. Sub-Sahara Africa

Sudan (Ms. Y. Fadlalla, Renewable Energy Institute): Experiments with the digestion of water hyacinths in Chinese, Indian, and butyl-rubber bag digesters were conducted in the late 1970's under a joint German-Sudanese water hyacinth control project. These digesters are being rehabilitated and additional research on the use of various feedstocks is being carried out by the USAID-assisted Renewable Energy Institute (p. 19).

Kenya (D. Day, University of Illinois, US): Under an AID project the University of Illinois will be assisting with the design of biogas systems for farm service centers being planned in Kenya by a U.S. agricultural services firm. The Ministry of Energy operates a biogas program in Kenya involving Indian-type digesters, and the University of Nairobi has a biogas research program.

Tanzania (K. Roeske, German Biogas Team, Tanzania): About 200 Indian-type digesters have been built in Tanzania. Biogas research is carried out by the Tanzania National Scientific Research Council and other organizations. A team from the German Biogas Extension Service

is based in Arusha; the team developed a portable plant made of two oil drums to demonstrate the principle of Chinese-type plants.

Uganda (J. Ilukor, Makerere University): About 25 biogas plants have been built in Uganda, of which 6 were installed by Makerere University. Successful tests have been conducted with the digestion of several plant materials including maize straw and elephant grass. Experiments will begin soon with the use of biogas in a 10 kw engine/generator set.

Rwanda (W. Edelman, bioenergy consultant, Switzerland): The Swiss government is funding a biogas installation at an agricultural school (p. 10) in cooperation with the USAID-supported energy research center, CEAER. FAO is supporting the construction of Chinese-type biogas plants in Rwanda.

Mauritius (J. Baguant, University of Mauritius): Biogas research has been carried out at the University of Mauritius since 1975; the present work is supported by the British government through the Commonwealth Science Council (p. 11).

Botswana (M. Khatibu, Rural Industries Innovation Center): The RIIC has built a 75 m^3 Indian-type digester to fuel a pumpset at a borehole (p. 7), as well as smaller Indian and Chinese digesters. A 120 m^3 digester, currently under construction, will be used for both water-pumping and cooking on a large farm.

Ivory Coast (U. Werner, OEKOTOP, Germany): A 400 m^3 horizontal digester with an unlined pit and an inflatable rubber gasholder provide fuel for the generation of up to 278 KWhr of electric power per day at a cattle-feeding center. The unit was funded by the German Agency for Technical Cooperation (p. 10).

Burkina Faso (A. Traore, Institute Superieur Polytechnique): About twenty 4 to 10 m^3 digesters have been built in the former Upper Volta including several units sponsored by the Belgian development assistance agency, AIDR, and the German Biogas Extension Service. A biogas research program has been undertaken by the Ministry of Higher Education and Research.

3. Asia

India (T. Moulik, Indian Institute of Management; J. Singh, AFPRO; S. Vyas, Punjab Agricultural University): After several decades of biogas technology development, a national biogas program was initiated in 1977; it is now coordinated by a Department of Non-Conventioanl Energy Sources (DNES) in cooperation with other national, and state agencies and non-governmental organizations. India now has about 280,000 biogas plants. Sixty percent are masonry digesters with floating steel gasholders which are known around the world as "Indian-type" plants; 40% are "Janata" plants which are a modified version of the typical Chinese displacement digesters. (pp. 6, 16, 25, 26).

Nepal (H. Gorkhali, Biogas and Agricultural Equipment Company; S. Pradhan, Department of Agriculture): There are about 1600 family-size plants and 24 community-scale plants in Nepal. About 55% are modified Indian-type designs and 45% are modified Chinese designs; these designs were shown on pp. 5 and 7 of the April 1984 BSR. The Biogas Company, which is partly government-owned, provides a 7-year operation and maintenance guarantee and 95% of the plants built in the past 7 years are still operational. The company has a staff of 140 and plans to build 2400 plants over the next three years. There are 50 plants in Nepal (including all of the community plants) which provide gas for 5 to 7 HP engines; most of these are used for rice milling.

Sri Lanka (M. Amaratunga, University of Peradeniya): There are more than 300 digesters in Sri Lanka; Chinese-type models are somewhat more numerous than Indian-type plants. A 90 m^3 plant provides gas for electric power generation at a rural energy center at the village of Pattiyapola sponsored by the UN Environment Program. The University of Peradeniya conducts biogas research and educational programs and operates an

integrated biogas system which provides cooking gas for about 100 persons (pp. 5, 27).

Thailand (Sompongse Chantavorapap, National Energy Administration): About 5,000 family-sized digesters are generating 1 to 2 m^3 of biogas per day for household cooking in Thailand. Ten community-scale plants produce 20 to 30 m^3 of gas daily which is used in a pumpset or engine/generator set. The National Energy Administration has provided full financing for 184 plants and one-third financial support for 3,300 plants; partial funding for the NEA biogas program has been provided by a USAID alternative energy project. A new alcohol plant in Thailand will include a large system to produce biogas from stillage (p. 19); studies are being made of biogas potentials in five types of agroindustrial plants.

Philippines (N. Orcullo, Ministry of Energy; C. Taganas, Maya Farms): There are at least 600 biogas plants in the Philippines; total biogas output is about 10,000 m^3 per day. At Maya Farms, the world's largest farm biogas system provides all of the electric power and heat energy for a 50,000-hog pork production and meat packing complex (p. 8); 24 other pig farms have biogas systems. A large distillery (p. 18) and an ice plant also use biogas. Five Philippine firms build various types of biogas plants (p. 11).

South Korea (D. Stuckey, Imperial College, UK): About 29,000 digesters were built between 1969 and 1975; most of these consisted of a concrete-lined cylinder and a floating gasholder made of wood lined with plastic. This program was discontinued in 1976, due primarily to the low gas production of these units in Korea's cold winters. Recent biogas activities have concentrated on village-scale heated digesters and low-cost batch digesters for the dry fermentation of straw and manures.

China (Li Jiazao, Chengdu Biogas Research Institute; V. Smil, University of Manitoba, Canada): Over seven million digesters have been built in China. Most of these are the fixed-dome type with adjacent displacement chamber. Due to the high gas pressure buildup under the masonry dome, there have been serious gas leakage problems with these digesters and a substantial fraction of the plants built in China are no longer in operation. Smil's paper indicated that the recent socio-economic changes in China, which have deemphasized communal agriculture and widened economic opportunities for individual peasant families, have decreased the family's incentive to invest in a biogas plant of uncertain reliability. Li's report indicated that the use of sealing paint has basically solved the problem of gas leakage due to poor-quality building materials. He indicated that Chinese research efforts are now emphasizing improvements in the productivity of the present digesters especially through various means of raising digester temperatures and the use of external gasholders to reduce the pressure within the fixed-dome digesters.

4. Latin America and the Caribbean

Overview (R. Caceres, OLADE): A recent survey by the Latin American Energy Organization indicated that there were 3,950 digesters in 21 Latin American and Caribbean Countries; three-quarters of the units were in Brazil. The next largest concentration was in Cuba, which had 552 digesters. The other 19 countries had 365 digesters at the time of the survey. Sixty-five percent of the surveyed digesters were Indian or horizontal plug-flow types, 25% were Chinese-type units, and 7% used other designs. About 40% of the digesters were not functioning regularly, but most of these were in startup phase or had solvable problems. About 7% of the units had been abandoned, due mainly to structural flaws or to poor locations too far from the sources of feedstock.

Brazil (A. Brandini, EMBRAPA): Brazil has about 3,000 biogas plants, of which 2,000 to 2,200 are operational. About 50% are Indian-type units, 35% are Chinese models, and 15% are other types including plastic bag digesters, masonry digesters with flexible covers, and other designs. About 40 villages have biogas-fueled generating sets. Fifty of Brazil's 500 distilleries are using Upflow Anaerobic Sludge Blanket (UASB) digesters to produce biogas from stillage.

Guatemala (L. Lopez, Ministry of Energy; L. Ingram, ICAITI; E. Zelada, INTECAP; A. Paniagua, Bioerg): There are about 100 digesters in Guatemala including 38 Chinese-type models, 34 horizontal digesters utilizing a design developed by ICAITI (p. 8), 20 batch digesters using a design developed by OLADE, and some larger units. Four Guatemala agencies are involved in biogas including ICTA, which operates agricultural research centers; ITA, a center for agricultural studies and training; DIGESEPE, the agricultural services arm of the Ministry of Agriculture; and INTECAP, a governmental technical and productivity institute. ICAITI, a Guatemala-based regional research institution, assists all four agencies.

Costa Rica (A. Umana, Ministry of Energy; G. Chacon, University of Costa Rica): A biogas coordinating group has been established to coordinate the rapidly developing biogas program which has produced 100 digesters in Costa Rica. Both the University of Costa Rica and the Costa Rican Technology Institute (ITCR) have developed extensive experience with plastic bag digesters; the univerity team has built 30 of these digesters (p. 7). A number of horizontal digesters have also been built in cooperation with ICAITI.

Mexico (A. Martinez, Institute of Electrical Research): IIE has built several family-sized biogas units and has designed a 40 m^3 horizontal digester which has been in operation for several years at an agricultural school (See p. 9 of the April 1984 BSR). OLADE's recent survey showed that there were 26 digesters in Mexico.

Bolivia (E. Medina, Nat. Institute of Rural Electrification): Eight biogas plants were installed under the OLADE Biogas program and there were a total of 17 plants in Bolivia by 1984. A recent survey examined farmers' attitudes regarding biogas.

Ecuador (E. Yanez, National Energy Institute): OLADE's survey showed that there were 28 biogas plants in Ecuador, of which 20 were Indian designs.

PART TWO: DESIGNS FOR BIOGAS PLANTS AND SYSTEMS

1. Chinese-type plants

Discussion of Chinese-type displacement digesters focussed on the means of limiting or ameliorating the leakage problems which have plagued these digesters. Amarantunga (Sri Lanka) outlined causes of leakage in the base and walls including inadequate thickness of the brickwork in the base, inadequate compaction of the earth below the base and of the backfill around the walls, inadequate structural connection between the base and walls, the upthrust of water in waterlogged areas, and the expansion of small cracks by tree roots attracted by the rich fertilizer in the slurry. He continued that leakage of gas from the gasholding dome can be caused by inadequate plasterwork, inadequate soil overburden on top of the dome to balance the pressure of gas from below, and the use of semi-vertical angles greater than 45°. L. Sasse (BORDA, Germany) stated that a masonry structure will never be gas tight unless it is continuously and uniformly under pressure; the design of a digester should be as spherical as possible, avoiding corners or other abrupt changes of shape.

D. Stuckey (Imperial College, UK) reported on efforts to reduce gas leakage in China by the use of well-trained technicians, concentrating on a smaller number of well-proven designs, and the wider use of cast concrete to provide greater structural strength. Singh (India) described the major efforts to train masons to build modified Chinese-type digesters. (p. 27).

Some of the modifications of the basic Chinese design have been motivated primarily by the need to limit gas leakage. A paper by B. MacGarry (Silveira House, Zimbabwe) described the use of 50 cm of water over the manhole cover of the digester to avoid the lifting of the lid by gas pressure within the digester. Singh noted that the manhole has been eliminated entirely in the Chinese-type "Janata" plants which are now widely used in India. The

manhole is needed in China for the semi-annual or annual cleaning of the digester which is necessary due to the use of plant materials along with animal and human wastes. In India, where only manure slurries are used, digester cleaning is not required. Gorkhali (Nepal) indicated that a similar modified Chinese design without a manhole is being widely used in his country; however, the digester sludge can be removed through a widened outlet chamber (See sketch on p. 7 of the April 1984 BSR).

Stuckey reported that the Chinese are now using small (1.0 to 1.5 m^3) plastic gas storage bags to reduce the gas pressure and gas leakage in the displacement digesters. Since the masonry does not have to hold such high pressures, savings in construction costs offset the cost of the gas storage bags. MacGarry described the use of patched rubber inner tubes from the tires of large trucks or buses as supplementary gasholders for family digesters in Zimbabwe. One such inner tube holds about 250 liters of gas, which is enough to cook a simple family meal.

During a field trip to the NRC digesters at the village of El Manawat, conference participants saw a modified outlet chamber which was designed to reduce the loss to the atmosphere of gas generated from slurry pushed up into the outlet chamber. The large volume and elevated postition of the outlet chamber and the rather narrow pipe connectiong it to the digester were designed to minimize fluctuations in gas pressure and reduce the movement of slurry in and out of the outlet chamber. An evaluation of this design feature is planned in 1985. (See sketch on p. 8 of the April 1984 BSR).

2. Indian-type digesters

Several presentations outlined factors which have limited the wider use of Indian-type biogas plants with floating steel gasholders. R. Ward (Miami University of Ohio, US) referred to the cost of the gasholders, corrosion problems, and the loss of heat from the digester through the gasholder. Corrosion can be reduced by using a modified design in which the gasholder floats in a ring of water rather than in the slurry, but this design increases the labor and material costs of the plant.

MacGarry found that welding and other metalworking equipment and the skills needed to produce steel gasholders were much less available in rural Zimbabwe than the skills and tools needed for the masonry construction of Chinese-type digesters. Participants from Nepal indicated that it is not feasible to transport steel sheets or gasholders for the Indian type plants to mountain villages in Nepal and that the Chinese-type plants were the only feasible models for many remote and roadless areas.

However, there seemed to be agreement that the high cost of the steel gasholders was the greatest barrier to the wider use of the Indian-type plants. Singh stated that the Chinese-type Janata plants are 30% cheaper in India than the plants with steel gasholders; this difference in cost is the main reason that 40% of the digesters in India are now modified Chinese designs. The current cost of the steel gasholder for a 8 m^3 Indian-type plant in Zimbabwe is about equal to the entire cost of a similarly-sized Chinese-type plant.

Sasse suggested that, since steel is the most expensive component, the dimensions of Indian-type plants in a given country should be designed to provide optimum use of the size of steel sheets which are available in that country. He noted, however, that the volumetric ratio between gasholder and digester depends on the desired retention time and other factors. Ward and Stuckey both noted that in the KVIC plants in India the height of the digester is between 2.5 and 4.1 times its diameter. This ratio was originally based on a desire to minimize the cost of the gasholder; however, one study showed that in order to minimize the total plant cost the height and diameter should be about equal.

Ward also outlined efforts to use other materials for floating gasholders. High-density plastic gasholders have been used in India; they resist corrosion and reduce heat losses, but they are about as expensive at present as the steel units.

Gasholders made of ferrocement have been tried in India and elsewhere. They are relatively inexpensive and resistant to heat loss, but are difficult to transport and subject to gas leakage problems.

G. Frettloeh (German Biogas Team, Barbados) described two 20 m^3 ferrocement gasholders which were built at a dairy farm in Barbados. The plant was only 500 m from the Atlantic shore; even with protective coatings, steel gasholders would have corroded very quickly due to the constant salt breeze. The gasholders were built on a mold consisting of twelve equal segments. Square welded mesh (75 mm x 75mm) was laid around the cylindrical part of the mold, shaped to form a wire basket, and welded together. Chicken wire mesh with 12.5 mm holes was wrapped around the rods. The basket was then plastered with mortar which was vibrated into the mesh with an orbital-action electric sander. After two days the mold was removed and the inside was plastered. When dry, the inside was painted twice with bitumen emulsion; overlapping sheets of aluminum foil were stuck to the second emulsion coat while it was still wet, and the foil was later covered with another coat of emulsion. The cost in Barbados of the ferrocement gasholders ($1,790) was 27% lower than the cost of comparable steel gasholders ($2,462).

Indian participants noted that another problem faced by the builders of both Indian-type and Chinese-type biogas plants in India is the limitation on the availability of cement. One response to this problem has been experiments with the use of plastic-lined earth pits in areas with firm silty soil; a fiberglass or steel gasholder is supported by a steel frame.

Khatibu (Botswana) reported on a 75 m^3 Indian-type biogas plant which provides fuel for a diesel pumpset at a borehole in Botswana. The plant was built by the Rural Industries Innovation Center for a 30-family cooperative. Gas production ranges from 30 m^3/day in summer to only 18 m^3/day in winter; the annual average is about 24 m^3/day or about .32 m^3/m^3/day. The gas is used in a 8 HP diesel pumpset, replacing 80% of the normal diesel fuel requirement. The unit operates up to 8 hours a day; it pumps an average of 36,000 liters of water per day, which is used by about 200 people and 2, 000 animals.

3. Plastic Bag Digesters

There was no report at Cairo directly from Taiwan, where plastic bag digesters have been most extensively used. However, Ward noted that the bag digesters were inexpensive compared to the Indian and Chinese types and easy to install and operate. Stuckey indicated that the exposed upper part of the bags easily traps solar heat; as a result, gas production rates as high as .6 to .7 m^3/m^3/day have been recorded in China and Korea. Ward pointed out that it is difficult to maintain the digesters at a relatively uniform temperature.

Chacon (Costa Rica) reported that 30 bag digesters have been built at the University of Costa Rica. They are assembled by students using 30 mil (1.0 to 1.2 mm) thick PVC material produced in Costa Rica. This thickness was established after experiments with both thicker and thinner plastic. The units are installed in U-shaped earthen pits lined with concrete blocks. Installation is relatively easy and the total cost of the digester is about $30/$m^3$.

The major continuing question concerning the plastic bag digesters is the extent of their vulnerability to degradation from ultraviolet rays in the sunlight. Although the Red Mud Plastic used for digesters in Taiwan contains wastes from aluminum production which are reported to inhibit ultraviolet degradation, the effectiveness of this material has not been documented; the Cairo discussions indicated degradation problems with one RMP installation in the Caribbean. Ward noted that several developing countries have had limited success with locally manufactured plastics due to degradation problems. However, Brandini (Brazil) stated that there were numerous bag digesters operating successfully in Brazil. The plastic used in Costa Rica contains no material or coating to protect it from ultraviolet rays; however,

the University of Costa Rica digesters are shaded by a galvanized iron roof supported by a wooden structure.

4. Horizontal Masonry Digesters

Ingram and Zelada (Guatemala) described the horizontal masonry digesters which have been developed by ICAITI and are being built in several Central American countries. (The basic design is shown in a sketch on p. 8 of the April 1984 BSR.) The sloping floor and walls are made of poured concrete beams filled in with concrete blocks; the original design had a slightly domed roof of reinforced concrete but it has now been replaced with a flat concrete roof which is easier to build and provides somewhat larger internal-gasholding capacity. Additional gas storage space is provided by separate steel or plastic gasholders. During the past 18 months 54 of these plants have been installed with ICAITI participation, and seven others have been built using a construction manual prepared by ICAITI. Most of the units have been built on small or medium-sized cattle farms; the construction costs, paid entirely by the individual farmers, are about $80/m^3. While most of the gas is used for cooking, gas from 13 of the systems is used partly for lighting and the gas is used in engines at 11 of the plants.

Conference participants visited a 50 m^3 heated horizontal digester built by the NRC biogas team at a poultry farm in the village of Shubra Kass. (The basic design of the brick "tunnel" digester was shown on p. 15 of the April 1984 BSR.) The plant originally included four mechanical stirring rods, but these proved ineffective; they have been replaced by a small compressor and a recirculation system which returns some of the biogas to the digester at each mixing port to provide a more efficient means of mixing and scum breaking. The digester is heated to 35°C by hot water circulating through five tubes just above the concrete floor of the digester.

In the initial plan the water was to have been heated by burning 10 to 15 m^3 of biogas per day in a gas water heater. Later a 4 KVA spark ignition engine-generator set was added to provide lighting for the chicken houses. The water for digester heating circulates through a heat exchanger around the exhaust pipe of the biogas-fueled engine. The gas is collected in a 20 m^3 floating steel gasholder; biogas to be used in the engine is filtered in a 200 liter drum of iron filings to remove hydrogen sulphide which could damage the engine. Heat loss from the digester is reduced by enclosing the digester in a plastic greenhouse. Although the final evaluation of the project has not been completed, the average gas production is estimated to be between 1.0 and 1.2 m^3 of gas per m^3 of digester per day.

A horizontal digester with a volume of about 320 m^3 has been designed by the NRC for the Aluminum Company of Egypt. The unit will operate on dung from about 500 cows at the housing complex associated with the aluminum plant. The digester will be heated through a combination of passive solar techniques and the burning of biogas. The system will provide cooking gas for about 200 households in the housing complex, and the effluent will be used for the reclamation of nearby desert land.

A paper by Obias and a presentation by Taganas (Philippines) described the horizontal concrete digesters which are used in the very large biogas complex at Maya Farms in the Philippines. The units have a rectangular cross-section; the walls, floor, and roof are of reinforced concrete. Several digesters are built together with common sides. The slurry enters the digester by gravity from a slurry sump over the inlet pipe; the sump volume is equal to 1/23rd of the slurry capacity of the digester, and the daily addition of the contents of the sump provides a retention time of 23 days. The digesters are stirred manually by stirrers along the length of the digester. The gas from the multiple digesters is collected in a series of floating steel gasholders which store the gas at a pressure of up to 18" (45 cm) water column. Maya Farms now produces at least 5,600 m^3 of biogas per day; it provides all the heat energy and mechanical and electrical power needed in the 50,000-head hog farm and associated meat-packing plant.

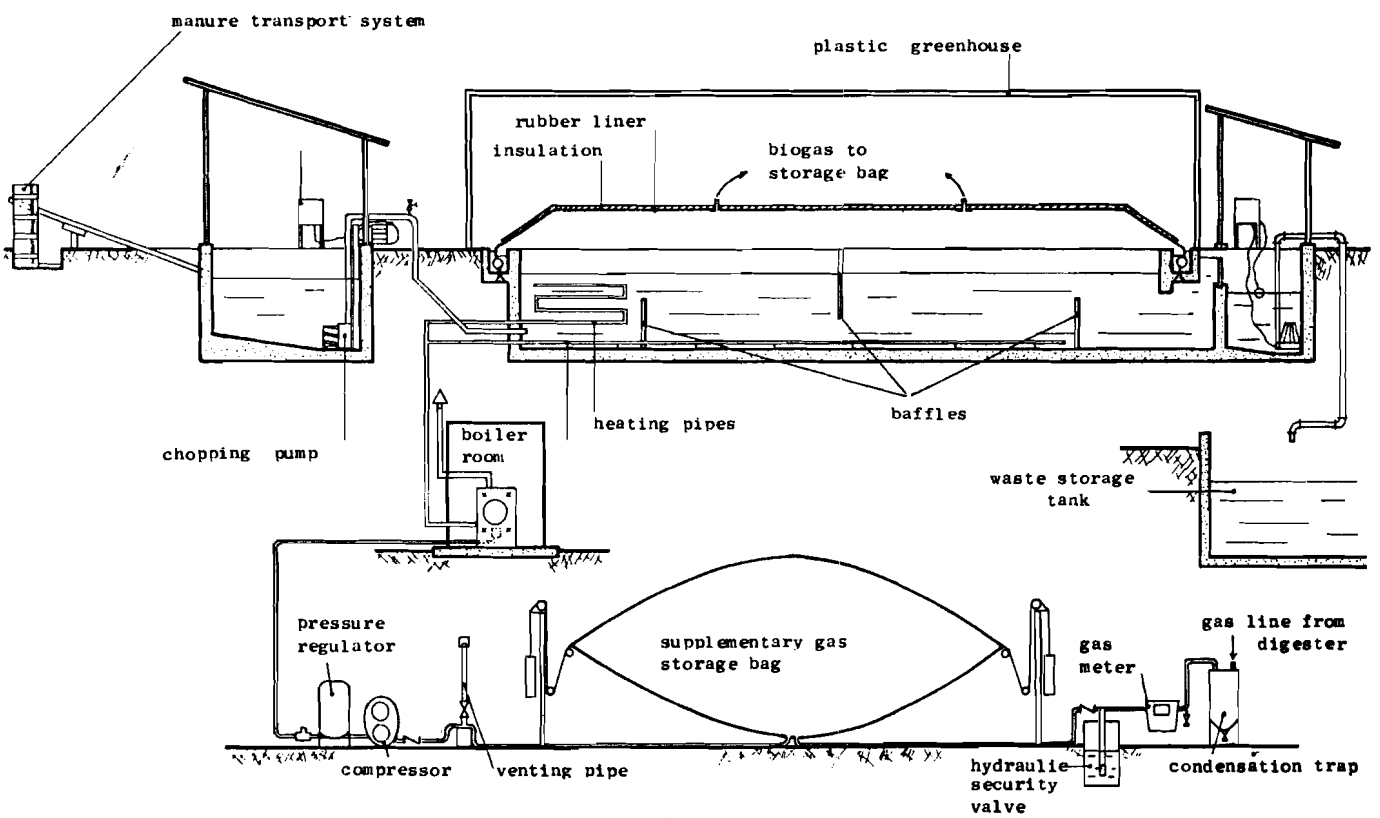
5. Masonry Digesters With Flexible Covers

F. DePoli (ENEA, Italy) described a relatively low-cost plug-flow digester which has been built near Bologna by ENEA, Italy's alternative energy agency. The unit uses about half of the manure from 120 dairy cows; it is removed from the barn daily by a mechanical scraper, collected in a 4 m^3 mixing tank, and chopped in a 11 KW chopping pump. The digester (shown below) is a rectangular concrete tank 13 m long, 3 m wide, and 1.75 m deep with a liquid volume of about 65 m^3. It is divided into four chambers by three fiberglass baffles which distribute the waste through the cross section of the digester and provide the same retention time for each loading.

The digester has an inflatable rubber cover which has a gasholding capacity of about 30 m^3. The cover is attached to the bottom of a 50 cm deep concrete channel around the digester which is filled with water to prevent gas leakage. Supplementary gas storage is provided by a 40 m^3 rubber gas storage balloon. Eight cm of rockwool insulation is laid on top of the rubber digester cover and a plastic greenhouse surrounds the entire digester; in a commercial unit, the greenhouse could be replaced with a simple plastic sheet to protect the insulation from the rain.

The digester is heated by a two-part heating system. A 100 m long coil of 1.5" (3.8 cm) diameter iron pipe rapidly heats the incoming slurry to the process temperature of 36 to 37° C in the first of the four digester chambers; the temperature is maintained in the rest of the digester by a 85 m long coil of 2" (5 cm) diameter polyethylene pipe. The coils circulate hot water heated by burning some of the biogas in a small boiler.

The capital cost of the plant exclusive of engineering and supplementary gas storage was about $19,200 or about $295/$m^3$: the cost could be considerably reduced in warmer countries through the use of a less elaborate heating system and reduced insulation. The gas output of the unit has reached 1.5 m^3/m^3/day and .41 m^3 per kg of volatile solids added. Two similar plug-flow plants are being built, and ENEA plans to publish design and construction manuals on the plug flow design.



P. Balsari (University of Milan, Italy) reported that a similar design was used for a small plug-flow digester with a volume of only 12 m^3 at the University of Milan. The digester was heated to 30°C using a 15 m^2 rubber heat exchanger of a type used in solar collectors and circulating water heated in a biogas-fired boiler. The daily load was .6 m^3 and the retention time was 20 days. The gas output was about 1.1 m^3/m^3/day.

D. Compagnion (University of Louvain, Belgium) described several concrete digesters with flexible covers which have been built by the University of Louvain in a Belgian biogas project in Burundi. The digester has a large surface area to minimize scum formation; the contents are mixed with a simple mechanical device near the exit end of the horizontal digester. The masonry structure is only partly buried in the ground in order to maximize exposure to the warm atmosphere; the black polymeric material of the digester cover absorbs solar heat. Where necessary to maintain a digester temperature of around 30°C, the digester is surrounded by a greenhouse of transparent plastic. The gas is stored in a separate bag.

A hexagonal 20 m^3 concrete digester with an inflatable plastic cover was described by Edelman (Switzerland). An initial unit has been built in a Swiss project at an agricultural school in Rwanda. The unit is fed with humidified solid pig manure supplemented by human wastes from an adjacent latrine; it is operated as a batch digester at a temperature of about 20°C and a retention time of about 63 days. One of the three planned units will be refilled in rotation every three weeks. Gas will be used for the school's kitchen or in a nearby cheese factory.

Small family-sized digesters with plastic covers are also planned in the Rwanda project; the cover will include chambers like those in an air mattress which will be filled with water to increase gas pressure from the small plants.

6. Other Digesters with Flexible Covers

Werner (Germany) described a 400 m^3 digester built for the German Agency for Technical Cooperation at a cattle fattening center in the Ivory Coast. The digester consists of an unlined pit dug in laterite soil; the pit is nearly sealed by the organic matter in the slurry, and only about 5% of the daily slurry loading is lost through seepage. The pit is covered by an inflatable gasholder of elastic synthetic rubber; the edges are attached to stay in the bottom of a water-filled concrete channel which surrounds the pit. The inflated cover holds about 80 m^3 of gas. (Additional information concerning this plant and its earlier operation with a lower loading rate was provided on pp. 19-20 of the March 1983 BSR).

The system in the Ivory Coast is fed with manure from about 300 cows; the average gas production is now about 240 m^3 or about .6 m^3/m^3/day. The gas is used in a 12 kW generator set. The present gas output is sufficient to operate the engine almost continuously and produce up to 280 kWhr/day. The power is used in the adjacent slaughterhouse.

Balsari presented the experience at the University of Milan with the use of a floating reinforced Hypalon rubber collector to recover additional gas from a 3,000 m^2 effluent pit downstream from a 750 m^3 digester. The pit receives 100 m^3 of slurry per day at a temperature of 30°C; the pit temperature ranges from 6° to 22°C depending on the season. The slurry and a total solids content of only .5% and a VS/TS ratio of 65%. It remains in the pit for a retention time ranging frm 22 to 37 days. After initial tests with a smaller floating collector, a 400 m^2 cover of 1.2 mm thick Hypalon is being tested; it is supported by polystyrene sections which allow the accumulation of gas under the cover. The gas is removed through a 160 mm diamter perforated PVC pipe using a piston pump driven by a 1 kW electric motor. The gas is used to produce electricity and heat in a cogeneration unit. Daily gas output during the initial weeks of operation in the fall of 1984 was .25 m^3

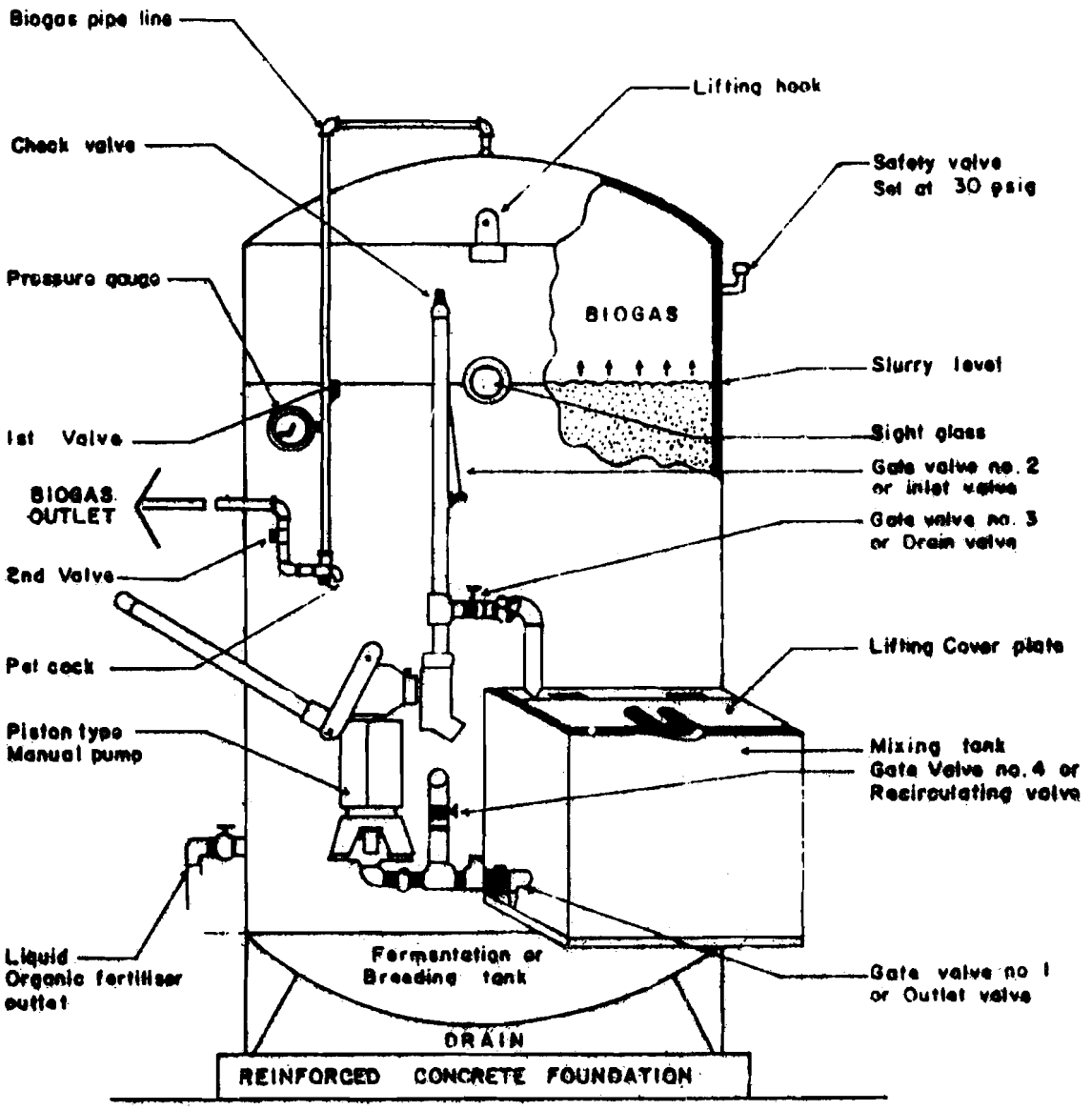
of gas per m^2 of covered surface. The pilot plant cost only about $15 per m^2 exclusive of the cost of the pit; a payback period of less than two years is expected.

7. Prefabricated Steel or Plastic Digesters

Conference participants heard reports from seven countries on the use of small aboveground digesters which had been prefabricated of steel or high-density plastic materials.

Orcullo (Philippines) reported that three firms in the Philippines are fabricating portable digesters consisting of small steel tanks. One firm produces units ranging in volume from 2 to 8 m^3 and in gas output from 1 to 8 m^3 per day; two other firms produce smaller units generating only about 1 m^3 per day. One of these prefabricated digesters is shown below.

E. Vincenti (SPI, Italy) described a system offered by Societa Politecnica Italiana. An insulated steel tank is heated by the natural circulation of water to a heat exchanger in the digester from a flat-plate solar collector located below the digester. The unit produces about 18 m^3 of biogas per day, which is collected in a separate floating steel gasholder. Sludge is removed every 10 to 15 days through large pipes and a sluice gate.



In hot tropical countries such aboveground steel digesters are adequately heated directly by the sun. The black-painted metal absorbs heat from the sun during the day, and the temperature drop at night is not excessive. K. Deepchand (Mauritius) reported that a 1.7 m^3 steel digester tested at the University of Mauritius maintained near-optimum temperatures. During a period in which ambient temperatures ranged from 21 to 25°C, the digester temperature remained close to 34°C except for occasional afternoon peaks above 40°C. Daily gas production was about .5 $m^3/m/day$ or about twice the output obtained in the laboratory at about 21°C.

F. Varagnat (GRES, France) reported that the Institute for Tropical Agriculture (IRAT) in France has developed an integrated livestock and grain production system for small farmers using biogas produced by 9 m^3 prefabricated horizontal steel digesters. The system was tested in Senegal on farms with about four stabled cows and two to four hectares of millet production. The digester was fed 60 to 120 kg/day of a mixture of cow dung and bedding material (millet stalks); the mixture contained 50% dry matter. The unit is heated by the tropical sun to 30°C and produces from 6 to 12 m^3/day (or .66 to 1.3 $m^3/m^3/day$), depending on the temperature and loading rate. The gas is used in a 5 to 10 HP diesel pumpset to irrigate two to four hectares.

Li (China) described experiments with small aboveground digesters designed for use only during the warmer months in areas of north China in which the average temperature is below freezing for nearly half the year. A .5 m^3 unit with a floating gasholder absorbed solar heat and maintained a digester temperature of about 30°C although ambient temperatures were only about 20°C; the average output from a mixture of horse dung and corn stalks with 14% TS was .63 $m^3/m^3/day$. A 2.5 m^3 jar-type steel digester obtained .68 $m^3/m^3/day$ from a mixture of the same feedstocks with 20% TS.

G. Chan (Energy Office, U.S. Commonwealth of the Northern Mariana Islands) described a 11.5 m^3 digester mad of 1/4" (.63 cm) thick fiberglass. The circular walls of the tank rise 12" (30 cm) above the slightly domed roof to form an open pressure tank which is connected to the slurry in the digester by a 3" (7.5 cm) diameter pipe. As in the typical Chinese digesters, gas accumulates under the dome and the pressure pushes slurry up through the pipe into the pressure tank or outlet chamber. However, the gas pipe is connected to another fiberglass tank which provides 4.5 m^3 of gas storage and reduces the pressure buildup within the digester; an open-ended manometer releases gas to the atmosphere if the pressure exceeds about 100 cm. The low-cost fiberglass digesters and gas storage tanks can be fabricated by small firms even in remote areas. They are not subject to corrosion or rot. The low capital costs can be repaid in three or four years.

Hong (North Korea) reported on the use of a 10 m^3 digester with a design similar to that in the Mariana Islands; the unit was made of a fiber resin plastic which has strength and durability and is easily installed or removed due to its light weight. The digester is heated to about 35°C by piling a thick layer of composting biomass around and on top of the digester (p. 17).

8. Integrated Systems

Three presentations dealt with systems in which the biogas plant is integrated into a complex agricultural, energy, and recylcling system.

Chan outlined the concept of an integrated system for a 4 to 5 acre (1.6 to 2.0 ha) family-size farm in which all of the wastes and residues would be recycled to produce most of the needed fuel, feed, and fertilizer. Wastes from livestock pens would be digested in the fiberglass digesters described above. The biogas would provide heat energy and electrical power for farm operations for a small workshop or processing operation. The effluent would be used (a) to produce algae for feeding to fish

and prawns, (b) in hydroponic vegetable production, and/or (c) as fertilizer for crops and trees.

Some of the conference participants visited an Integrated Renewable Energy System which is being completed at a modern dairy farm at Fayum by the Cairo University faculties of agriculture and engineering. The systems will include three circular 15 m^3 concrete digesters which will be heated by flat-plate solar collectors. Each digester will use a different mixing device including a wind-powered Savonius rotor, an electric mixer powered by photovoltaic cells, and a manually-operated mixing device. Each digester will be fed about .5 m^3 of slurry per day with 8% total solids; the retention time will be 30 days. Anticipated total gas production is 22.5 m^3/day or about .5 m^3/m^3/day from the total digester volume of about 45 m^3.

The gas from the Fayum digesters will flow through an iron oxide scrubber to remove hydrogen sulfide and through a lime water tank to absorb carbon dioxide; when the gas flow is switched to a second lime water tank, the CO_2 will be driven off by heating the first tank with solar energy from flat-plate collectors. The released CO_2 will be piped to the system's algae ponds, where it will speed the growth of algae to be used for fish feeding. The algae will also be fed some of the slurry from the digesters. Digester sludge will be used for fertilizer.

Water for the Fayum system will be pumped by a water-pumping wind mill. A wind-powered 2 kW generator will provide electric power when the wind speed is more than 5 mph; biogas will be used for power generation when the wind-powered generator is not operating. The purified biogas, which will be relatively pure methane, will be stored in two 10 m^3 floating steel gasholders and will be used is 2kW and 1 kW spark-ignition generating sets. Anticipated maximum electric power output with biogas is 28 kWhr/day or about 1.2 kWhr per m^3 of gas.

Vincenti outlined a large integrated agricultural system being developed by four Italian firms for a large poultry, fruit, and vegetable complex in Sassari, Italy. Biogas is generated from the droppings of 100,000 laying hens in a fully automated egg production system. The two-stage digestion unit includes a 900 m^3 first-stage steel digester and a 200 m^3 second-stage steel digester with a 140 m^3 floating steel gasholder. The unit produces 1600 m^3 of biogas per day or 1.45 m^3 for each m^3 of total digester volume.

When the complex is completed during 1985-6, the gas will be used in cogeneration units to produce about 2.7million kWhr of electric power annually or about 7500 kWhr/day. About 1.4 million kWhr will be used each year to operate the poultry facility, while about 1.0 million kWhr will be used for heating 5,000 m^2 of greenhouses for vegetable production. Pumping water for the greenhouses and a 2.5 ha orchard will use 135,000 kWhr, and 160,000 kWhr will be used in a plant for packing and preserving the fruits and vegetables. Effluent from the biogas plant will be used as fertilizer in the greenhouses and the orchard.

9. High-rate Digesters

There were only a few references in the conference presentations to the several types of high-rate digesters which are being used in some countries for the digestion of agroindustrial wastewaters. A three-phase digestion system developed in Egypt to produce biogas from kitchen refuse at an army camp (p. 18) includes a supplementary fixed-film digester following a conventional but heated digester. The supplementary "anaerobic filter" produces more than one cubic meter of gas for each cubic meter of volume of the fixed-film unit. There were also references to the Upflow Anaerobic Sludge Blanket (UASB) digesters being used to produce biogas from stillage at distilleries in Brazil and to the production of biogas from coffee pulp juice in a UASB digester in a research institution in Guatemala (p. 19). Information on several high-rate digestion systems utilizing agroindustrial residues was provided on pp. 19-22 of the April 1984 BSR.

PART THREE: OPERATION OF BIOGAS PLANTS

The inadequacy of the published information on the operating parameters and performance of biogas plants was noted in several presentations. Stuckey (UK) commented on the lack of adequate field data on the performance of digesters under a variety of operational conditions and with different feedstocks. These limitations have inhibited the careful comparison of the various operating options, complicated the economic assessment of biogas plants, and led to the over- or under-designing of biogas plants. Both Stuckey and T. Parkasam (Metropolitan Sanitary District of Chicago, US) felt that comparative assessment of digester designs and operating techniques were restricted by the lack of a uniform system for measuring and reporting various operating parameters. El Halwagi (Egypt) recommended that a concentrated effort be made to standardize the reporting of biogas data in order to facilitate comparisons among units in different regions.

The conference presentations provided useful data and the basis for some comparisons on four types of operating parameters: (a) solids concentrations in the slurry, (b) retention times, (c) mixing of the substrates, and (d) techniques for raising digester temperatures.

1. Solids Concentrations

The presentations indicated a rather wide range of experience and opinion related to the optimum percentage of total solids in the slurry. Ward (US) noted that when a water flushing system is used at pig farms, the slurry arrives at the digester with a low percentage of total solids. D. Bellamy (University College, Cardiff, UK) indicated that about 3% solids is typical for British farms using large amounts of flushing water and that the ideal concentration of about 9% is unattainable at such farms; however, he advocated the planning of future systems to minimize the dilution of the manure and thus enhance gas production. A paper by Obias (Philippines) states that the slurry sumps on the digesters at Maya Farms have screened outlets to retain solids and allow excess washing water to overflow. The slurry is added to the digester when the concentration reaches approximately one part manure to two parts water. Maya Farms is also using "anaerobic filter" digesters, with gravel as the filter medium, to obtain additional gas from liquid wastes with low solids content.

In contrast, limitations on the availability or accessibility of water in many situations in developing countries have led to substantial interest in the use of higher solids concentrations in digesters. Sasse (Germany) commented that insufficient water has been added to the dung in some villages in India where the women must carry water a considerable distance for slurry mixing. Stuckey reported that research at Cornell University demonstrated that fermentation can proceed at total solids concentrations up to 32%. Li (China) stated that up to 1.6 m^3/m^3/day of gas has been obtained in batch digesters from a mixture of animal dungs at 30°C and 20% solids.

Such "dry" fermentation would greatly reduce the water requirements for biogas production, a significant factor in arid areas and in other places where water is not readily accessible. Vyas (India) felt that a major goal of digester design work should be to enable the use of slurries with higher solids concentrations. El Halwagi's conference summary stated that such "dry" digestion should be investigated in greater depth; in addition to saving water, such digesters could use dry agricultural residues which are abundantly available and would produce a relatively dry organic effluent which would be easier to handle than a wet slurry.

Two other approaches to the water problem were utilized in projects carried out in Egypt. Hamad noted that the water problem can be reduced by the use of urine as well as dung in the digester. He described a sloped concrete floor which was added to the cow shed at a NRC-built plant to drain urine into the slurry mixing chamber. The addition of water to bring the solids concentration down to 8 to 10% is necessary only in the summer, when the

manure dries quickly. Researchers at the agricultural faculty at Fayum of the University of Cairo tried using diluted sea water in digesters. The results suggested that sea water could provide some of the water needed for biogas production if it were sufficiently diluted with fresh water or if the retention time were long enough to allow the methane-forming bacteria to become acclimated to a higher level of salinity.

2. Mixing

Stuckey noted that most of the technical literature on biogas indicates the need for mixing in digesters (a) to maintain uniform substrate conditions, (b) to prevent scum formation, and (c) to prevent the depositing of solids. However, he recognized that many digesters have operated satisfactorily on animal manures without the use of any device specifically designed for mixing. It has been widely assumed that an adequate degree of mixing is provided in Indian-type family digesters by the vertical movement and rotation of the steel gasholder and in the Chinese-type digester by the movement of the slurry in and out of the displacement or outlet chamber.

M. Ebrahim (Minia University, Egypt) reported that in a laboratory digester the use of a three-armed steel mixing device with swinging baffles had permitted a 20% decrease in retention time with a 25% increase in gas output. Hamad stated that when a mechanical stirring rods proved ineffective at the 50 m^3 digester at Shubra Kass, poultry manure mixed with bedding material induced flotation and settling problems and blocked the digester. The problem was solved by the recirculation of some biogas via a small compressor: the presence of some mixing points which are distributed along the digester's length did not adversely affect the plug-flow pattern of operation.

A large kitchen refuse digester at an army camp in Egypt (p. 18) is mixed by circulation of the slurry with a pump for 25 minutes three times a day and by recirculation of biogas through the slurry for 25 minutes once a day. Alaa el Din reported that, when slurry circulation and gas recirculation were stopped for ten days, the gas output was reduced by only about 8%. He also cited experiments in the U.S. which showed that the gas output with intermittent mixing was only about 8% less than with continuous mixing. Prakasam stated that the net advantage of mixing community and industrial-scale digesters should be studied to determine if the additional energy production exceeds the energy required for mixing.

Both Stuckey and Prakasam noted that some studies, including tracer studies conducted by the NRC in Egypt, have indicated that there is considerable "dead" space in unmixed digesters and that both the active volume of the digester and the retention time are less than had been assumed. El Halwagi's conference summary noted that there is very little information available on the effect of mixing on retention time and digester performance; he called for further studies to determine the actual retention time in typical digesters in developing countries and means of improving the retention time by judicious use of mixing.

3. Retention Times

Sasse conceded that digesters operating at optimum temperatures and other optimal conditions work well with a retention time of 22 to 30 days. However, he found that the temperature in family digesters in central India was about 28° rather than the 35°C which is usually considered optimum for anaerobic digestion. Tests near Poona in India proved that at 28° a retention time of 30 days does not permit the farmer to obtain the maximum gas from his limited feedstock. Stuckey indicated that in China a typical retention time for a digester operating at about 25°C would be about 60 days. Vyas found that a 50-day retention time was needed in northern India during winter months in a 75 m^3 Indian-type community digester. However, Ward cited indications that most of the organics are degraded during the first 15 to 30 days; he felt that a 50-day retention time could not be justified if maximum gas

production is the primary objective. He noted that a longer retention time means a larger and more expensive digester.

Increasing the loading rate (and thus decreasing the retention time) decreases the percentage of volatile solids which is degraded during the process. D. El Dhawarby (NRC, Egypt) reported that at 35° the percentage of volatile solids reduction from a 8% TS cow dung slurry was about 32% with a 30-day retention time but was only 23% with a 20-day retention time. Normally, increasing the loading rate also increases the yield of gas per unit of digester volume. However, Alaa El Din found that the optimum loading for the large kitchen refuse digester (p. 18) was 2.6 kg of volatile solids per m^3 of digester and that a higher loading rate (and lower retention time) produced a decrease in the daily gas output.

There were several indications that longer retention times are necessary for substrates containing a higher percentage of total solids and/or a high percentage of lignocellulosic material.

4. Digester Temperatures

The effect of temperature on the digestion process was documented in several papers. D. Mahin (Bioenergy System Reports, US) stressed that most of the unheated and mainly underground digesters in developing countries are operating at temperatures which are near the temperatures of the earth and are thus 10° to 20°C lower than the optimum temperature for anaerobic digestion. In latitudes near 25° (North or South) gas production in winter is usually only one third to one half the output in summer. Ward stated that between 15° and 35°C every 10° increase in temperature roughly doubles the rate of the reaction. Hamad reported that increasing the slurry temperature only 4° to 5°C nearly doubled gas production. Although the annual temperature variation in Zimbabwe was less than 10°C, MacGarry found that the output of a Chinese-type digester in the warmest month was three times that in the coldest month.

There were several reports on the use of plastic "greenhouses" over the digesters to reduce heat losses. Chacon (Costa Rica) indicated that plastic greenhouses are built over plastic bag digester in higher altitude areas in Costa Rica to prevent excessive heat loss during the cold nights. On sunny days the greenhouse also acts as a passive solar air heater; the NRC team in Egypt reported that maximum air temperatures inside several greenhouses were 20° to 25° higher than the ambient temperature. However, the extent to which this increased air temperature around the digester results in higher slurry temperatures depends on the design of the digester. The NRC team in Egypt reported that the gas production from digesters with greenhouses was about 50% higher than from digesters without greenhouses, but some participants indicated doubt that this increased output was solely a result of the use of the greenhouses.

Pradhan (Nepal) documented the insulating value of the greenhouses in cold climates when used with other insulating material. He compared gas output from an uncovered Chinese-type digester with that from two Chinese-type plants which were insulated with paddy straw and covered with white plastic greenhouses. Output from a digester with greenhouse which was fed slurry at ambient temperatures was 40% higher than that from the uncovered digester. However, the output from a digester with greenhouse which received slurry heated to 35°C was only 28% higher than that from the uncovered digester. Adding heated slurry apparently caused rapid changes in digester temperatures; such fluctuations have an adverse effect on the digestion process. DePoli (Italy) reported that the greenhouse used over the heated digester described on p. 9 had not proved effective and would be replaced in future models with a plastic sheet to protect the rockwool insulating material from the rain.

A few biogas plants discussed at Cairo have flat-plate solar collectors to heat water for digester heating coils: (a) Vyas reported that on sunny days coils filled with solar-heated water were used to heat a

75 m^3 digester at Punjab Agricultural University. The average January digester temperature was increased by 7°C and the gas output was doubled. However, the cost of a solar water heater capable of maintaining the digester at about 30°C during the winter in northern India proved to be about equal to the cost of the digester. (b) Li reported that a solar collector had been installed on the top of the displacement chamber of a typical Chinese digester to heat the slurry moving temporarily into the displacement chamber as gas pressure accumulates; the digester temperature was increased by 3 to 5° and gas output was raised by 25% in winter and from 30 to 100% in summer. (c) A 15 m^3 typical Chinese digester is heated with an internal heat exchanger in another experiment in China; the heating water is circulated through a 27 m^2 flat-plate collector on the roof of an adjacent building using a 1kW (presumably electric) water pump. The average digester temperature is about 33°C and the gas production rate is about .40 m^3/m^3/day.

El Halwagi's conference summary indicated that both active and passive solar techniques appear to have potential for raising digester temperatures without large capital investments; however, more information is needed on the optimum design and effectiveness of these systems.

D. Sood (Viking Energy Co., US) reported that the most popular technique for heating Chinese-type digesters in Nepal is by the composting of wastes on top of the digester. Composting paddy straw above the units raised temperatures inside the digesters by 9° to 11°C above the ambient temperature even during the coldest season. Hong (North Korea) indicated that a 2 m thick pile of compost around and over an aboveground tank digester (p. 11) maintained a temperature near 35°C during the cold winters in his country. Additional compost must be added every 15 days. Li reported that a 1.5 m thick layer of rice straw is used to insulate digesters in China's Liaoning province where ambient winter temperatures are around 5°C but soil temperatures are only about 9°C.

Vyas plans to burn 60 to 80 kg of rice straw per day to heat water for the warming of a series of digesters at Punjab Agricultural University. The total digester capacity will be 340 m^3; the units will receive feedstocks with 16 to 17% solids and are expected to produce about 140 m^3 of gas per day or about .41 m^3/m^3/day.

In larger systems some of the biogas can be burned in a boiler or water heater; the hot water is circulated through a coil in the digester. Prakasam pointed to the need for careful study of the net benefit of using some of the biogas to heat community and industrial scale biogas plants in developing countries. DePoli (Italy) reported that from 25% to 65% of the biogas produced by the ENEA plug-flow digester (p. 9) was used to heat the digester to 37°C; the percentage of biogas needed depends on the loading rate and the ambient temperature. A large kitchen refuse digester at an army camp in Egypt (p. 18) requires 46 m^3 of biogas per day for digester heating in mid-winter and uses about 25 m^3/day to heat the unit in spring and fall. However, the biogas needed for heating in winter is only about 18% of the average daily production of about 250 m^3/day, and only about 10% of the gross production is required in spring and fall.

Mahin stressed that, if the biogas is used in an engine or engine/generator set, the best means of digester heating is with waste engine heat. In a biogas-fueled generating set only about 25% of the energy is converted to electricity. If the engine is water cooled, the digester heating coils can be connected to the engines cooling system. Exhaust heat can also be recovered. Conference participants saw a simple heat exchanger around the exhaust pipe of a 4 KVA generating set at the NRC-built biogas plant at Shubra Kass; water circulated through the heat exchanger heats the 50 m^3 digester. Sood reported that the use of waste heat from a 7 HP biogas-fueled rice mill increased biogas output from a village digester in Nepal by 45%. Bellamy said that exhaust heat from a 20 KVA generating set maintains a temperature of about 35°C in a 350 m^3 digester at a pig farm in England.

PART FOUR: FEEDSTOCKS OTHER THAN ANIMAL MANURE

1. Crop Residues

Crop residues and other plant material are usually mixed with animal dung and human wastes in the typical digesters in China, but their use in digesters is rare in other developing countries. Li (China) reported that 30,000 digesters in Sichuan province are being fed with a layering technique which permits the charging of two-thirds more crop stalks and increases gas output by about 25%.

Rather high gas rates (.56 to .96 m^3/m^3/day) have been obtained in China from mixtures of corn stalks with pig dung and horse dung. Other experiments in China in batch digesters showed that during the first 20 days twice as much gas is produced from cotton stalks as from pig dung, although the total gas potential from pig dung is higher. Gas output from rice straw was somewhat higher than that from pig dung during the first 60 days.

2. Urban Residues

Alaa El Din (Egypt) reported on a large three-phase biogas system which produces cooking gas from kitchen refuse at an Egyptian army camp. The system was built by the Ministry of Agriculture's biogas group, in cooperation with the Ministry of Defense. The process begins with a one-day acid-formation phase in a 6 m^3 inlet tank; it receives about 480 kg/day of residues consisting of pieces of bread, vegetable and fruit residues, and cooked food. The feedstock is ground and mixed with 5 m^3 of liquid effluent from the plant's final phase. The slurry is mixed with manual stirring rods.

After a day in the inlet tank, the acidified slurry is fed to the 130 m^3 rectangular concrete digester which is divided into four sections by baffles. The digester is mixed by a combination of slurry circulation and gas recirculation (see p. 15). Except in summer, the digester is heated by burning some of the biogas in a boiler and circulating some of the gas through coils in the digester. The retention time in the main digester is about 22 days.

As fresh slurry is added daily, 6 m^3 of effluent flows out into a 20 m^3 supplementary "fixed film" digester. It contains an iron skeleton holding 24 one-centimeter thick polyurethane sheets; the formation of a fixed film of methane producing bacteria was accelerated by seeding with sewage sludge. The effluent remains in the fixed film digester for an additional 3.3 days.

The system was operated for about six months without the fixed-film digester. Gas production rates during this period averaged 1.035 m^3 per m^3 of digester per day and .937 m^3 per kg of volatile solids added. The addition of the fixed film digester increased average gas production to 1.602 m^3/m^3/day and the output has reached 2.3 m^3/m^3/day during several periods; the average gas production is just over 1.0 m^3 per kg volatile solids added.

The gas is used for cooking in the army camp, replacing 165 tons of kerosene each year. The world market value of the displaced kerosene is more than twice the construction cost of the biogas system, and the payback period for the system was thus about six months. The success of this project has encouraged army authorities in Egypt to plan an expanded biogas program for army camps.

DePoli (Italy) reported on experiments at the University of Venice with the digestion of organic urban wastes using a 3 m^3 pilot digester. The hand-classified feedstock was shredded and mixed with sewage sludge in a homogenizer to form a slurry with about 20% total solids. Gas yields varied from 1.8 m^3/day (.6 m^3/m^3/day) from feedstock with only 16% organic matter to 3.5 m^3/day (1.18 m^3/m^3/day) from feedstock with 90% organic material. Modifications are being made in a mechanical mixer to deal with persistent scum accumulation which increases in depth as the percentage of organic matter in the feedstock increases.

3. Distillery Residues

Brandini (Brazil) stated that about 50 of Brazil's 500 distilleries are using Upflow Anaerobic Sludge Blanket (UASB) high-rate digesters to produce biogas from stillage; the gas is normally used in the plants as a boiler fuel. Orcullo (Philippines) described a 1600 m^3 steel digester which is producing about 2200 m^3 of biogas per day from stillage at a large distillery.

Sompongse (Thailand) stated that a large biogas plant under construction at the Thai Alcohol plant will recover biogas from stillage and provide half of the energy needed by the 200,000 liter/day distillery. The value of the expected gas is estimated about US$2.5 million per year.

The report by Ms. Fadlalla (Sudan) indicated that the National Council for Research in the Sudan has sponsored laboratory studies of biogas generation from molasses and stillage; the results will be used in designing a medium-sized digester at a sugar factory.

Umana (Costa Rica) noted that the Ministry of Energy of Costa Rica is working on plans for a 1000 m^3 digester to be installed at the national distillery.

4. Other Agroindustrial Residues

Sompongse also reported that the National Energy Administration in Thailand is studying the potential for biogas production from the waste waters produced by five agroindustrial plants including a paper mill, a fruit cannery, a sugar mill, a tapioca starch plant, and an alcohol distillery. The studies are supported by the U.S. Agency for International Development and by the Belgian and Italian governments.

J. Calzada (ICAITI, Guatemala) described experiments at the Central American Research Institute for Industry with the anaerobic digestion of liquid agroindustrial wastes. Using a reticulated polyurethane foam digester, 1.91 m^3/m^3/day was obtained from fresh banana trunk juice with a loading rate of 3.5 kg VS/m^3 and a retention time of only three days. Up to 4.58 m^3/m^3/day of biogas was obtained from acidified coffee pulp juice using an Upflow Anaerobic Sludge Blanket (UASB) digester with a very high loading rate (22 kg VS/m^3) and a retention time of only two days. (See pp. 22-23 of the April 1984 BSR for more infomation on UASB digesters.)

A paper by Deepchand (Mauritius) described tests of mixtures of sugarcane residues (bagasse and sugarcane tops and leaves) with cow dung. Gas production was lower from the mixtures than from 100% cow dung during the first 50 days; however the output from the mixtures exceeded that from just dung in the next 50 days, due apparently to the gradual degradation of cellulosic material.

5. Other Biomass

Orcullo reported that the Bureau of Energy Development in the Philippines is planning a pilot project to demonstrate the potential for biogas production from water hyacinths by industries located along waterways which are heavily clogged with the aquatic plants. Beshir (Sudan) reported on laboratory tests of the digestion of water hyacinths at the Renewable Energy Institute in Sudan. Using a loading rate of .779 kg VS/m^3 and a retention time of 30 days, optimum gas production was obtained at 37°; at that temperature the 4 liter digesters produced 70.3 liters in 90 days or about .19 liter/liter/day.

Philippine agencies have sponsored laboratory studies of the production of biogas from Sargassum Sp., a marine algae which is abundant along the Philiippine coasts. The Bureau of Energy Development is planning a pilot or semi-commercial project to demonstrate biogas production from the algae.

Fermentation experiments have been conducted at the Institute Superieur Polytechnique in Burkina Faso on the use Calotropis procera, a common latex-producing plant in arid areas. The experiments indicated that the plant could be an important biomass source for biogas production.

PART FIVE: BENEFITS OF DIGESTION SYSTEMS

There was a consensus among conference participants that digestion systems must be evaluated as sytems providing a combination of several types of benefits, rather than simply as energy systems or waste management systems. Conference papers reviewed benefits from biogas utilization, benefits from effluent utilization, and health benefits.

1. Benefits of Biogas Utilization

The numerous advantages of biogas as a cooking fuel were outlined in papers by DuMouchel (Thailand), MacGarry (Zimbabwe), and Alaa El Din (Egypt).

Biogas provides a more modern and less laborious way of cooking. It is much quicker than burning wood or other biomass; for example, it permits the quick preparation of breakfast before the farmer leaves for the fields. By reducing the time required for the collection or preparation of fuel and for cooking, the biogas system frees the housewife for more productive activities. The use of biogas eliminates the odor, disease, and insect problems associated with the preparation of cow dung cakes for use as fuel. It ofter saves straw and crop stalks, which would otherwise be burned, and permits their use for fodder and silage. If wood has been used as a fuel, the wide use of biogas plants can help limit deforestation. The elimination of smoke from the burning of wood or dung cakes reduces the high risk of eye irritation and disease.

Mahin (US) reviewed the growing use of biogas as a fuel for engines and electrical generating sets around the world. He noted that the most common direct use of biogas fueled engines is for pumping water - for crops, for livestock, and for people. Engines operating mainly with biogas are also providing direct mechanical power for stationary machinery for rice milling, grain threshing, chaff cutting, and feed grinding. Electrical power is being generated with biogas in a number of developing countries as well as in North America and Europe.

He reviewed the conclusions of the study on "Mechanical and Electrical Power from Biogas in Developing Countries" to be published by the AID Bioenergy Systems and Technology Project in the spring of 1985. Biogas power systems use proven technology which has been amply demonstrated in many developing countries. The use of this technology is not restricted by any major unsolved technical problems, although some system design questions remain to be resolved. At present the wider use of these systems is inhibited by the limited international sharing of experience with such systems, by the lack of consensus on the best designs for digesters and other components, by the low productivity of the unheated digesters normally used in developing countries, and by the high cost of the large digesters which are required to compensate for these low volumetric gas production rates. All of these problems could be solved through more effective international communication and cooperation among those with experience with these systems.

2. Fertilizer Benefits

The value of the digester effluent as fertilizer was stressed at various stages of the conference. V. Smil (University of Manitoba, Canada) stated in the opening session that the anaerobic fermentation of farm wastes offers a unique opportunity for the return of organic matter to the soil; he noted that the more effective utilization of these wastes was the most important motivation for the construction of over seven million digesters in China. Alaa El Din pointed out that the need for organic matter had become especially urgent in Egypt since the erection of the High Dam at Aswan eliminated the deposit of organic matter on the soil during the previous annual flooding of the Nile. A discussion group chaired by A. Binger (Jamaica) stressed the importance of the recycling of organic wastes to meet the urgent need for fertilizer in the expansion of food producton in many countries.

Participants from Thailand, Philippines, Ecuador, and Jamaica noted that the effective use of digester effluent for fertilizer is limited by the farmers' lack of experience with the use of manure as fertilizer and/or lack of understanding of the benefits to be obtained from the use of digester effluent as fertilizer. In part, these problems arise from the lack of full documentation of the fertilizer value of the effluent. The papers presented at the conference provided some of the needed data and yet demonstrated a need for further studies which evaluate the effect of the numerous methods available for the use of manure and digester effluent.

Hamad (Egypt) pointed out that the large volume of the effluent, containing a low percentage of solids, limits the farmer's ability to transport it to the fields. One solution is to allow the slurry to dry in the air and use the dried solids as fertilizer. H. Capener (Cornell University, US) noted that Egyptian farmers with biogas plants were glad to be able to carry only the flaky dried effluent to the fields rather than the much heavier traditional mixture of dung and soil from the cow shed. However, Ward (US) and others noted that the drying of the effluent (or even the storage of the liquid for considerable periods in open tanks or lagoons) resulted in the loss to the atmosphere of a large percentage of the nitrogen which is in the form of ammonia, with a corresponding loss in fertilizer value of the effluent. Moawad (NRC, Egypt) reported that the air drying of slurry resulted in the loss of 29% of its original nitrogen content; however, tests showed that the air-dried slurry was superior to slurry which had been absorbed by silt and to composted slurry.

Bellamy (UK) described the use at a farm biogas plant in England of a vibrating screen to remove about 20% of the solids from the effluent. The solids were used for soil conditioner or as an animal feed additive (p. 22), while the liquid fraction is used in a pumped irrigation system. He noted that this method of fertilization had many advantages over the traditional manure-spreading methods including more uniform distribution of the fertilizer and the elimination of soil compaction by the tractors pulling the manure wagons.

Hamad noted that, if low cost equipment for the separation of solids form the effluent were available in arid developing countries, the solids could be used as fertilizer and the liquid fraction could be recycled to the digester to decrease the need for fresh water. S. Ghosh (Institute of Gas Technology, US) also listed the development of cost-effective and simple effluent dewatering processes among the important research needs in this field.

Several papers described the extensive research on the use of effluent as fertilizer conducted in Egypt by the National Research Center (NRC) and by the Ministry of Agriculture (MOA). The NRC conducted tests in pots of the effects of using fresh slurry, air dried slurry, a mixture of silt and slurry, composted slurry, farmyard manure, and fresh cow dung on virgin sandy and clay soils; all applicatons were at the rate of 2% on a dry basis. The MOA carried out field tests comparing applications containing comparable amounts of nitrogen of fresh effluent, stored mixtures of effluent and soil, and chemical fertilizers. The tests covered several types of crops:

Maize: In the MOA tests the fresh digester effluent proved to be a better fertilizer than urea or stored mixtures of effluent and soil. In tests with applications providing 140 kg of N per hectare, the traditional mixture of urea and earth compost produced 7 tons per ha, a 1:1 mixture of stored effluent and soil produced 7.43 tons/ha, and fresh effluent produced 9.50 tons/ha. The NRC tests indicated that the use of effluent had a depressive effect on the growth of maize seedlings; this effect was not observed if the effluent was added five to 10 days before planting, apparently due to the decompostion of toxic materials by soil microorganisms.

Wheat: The application of fresh effluent in the MOA field tests at the rate of 142 and 215 kg of N per ha resulted in increases in the grain yield by .857 and 1.462 tons/ha respectively compared to the use of the same level of N in the form of

ammonium sulphate. The straw yield was also higher. In the NRC pot tests the grain output in grams per pot from sandy soil was higher with dried slurry (15.27) than with fresh slurry (13.2); however, both slurry applications produced substantially more grain than compost (11.79), fresh dung (11.08), farmyard manure (9.64), and a mixture of slurry and silt (8.93). Yields were substantially higher in clay soil; the best yield was 26.85 with dried slurry, followed by 23.17 with a mixture of slurry and silt. In other NRC pot tests the grain yield in grams per pot was 5.91 with a silt/slurry mixture, 5.30 with fresh slurry, and 5.29 with urea. In NRC field tests, the applicaion of digester slurry at the rate of 5 tons/acre gave almost the same yield as the use of farmyard manure at the rate of 20 tons/ha.

Rice: In the MOA field tests the use of digester effluent at a rate of 107 kg N/ha (the recommended N level for rice) produced a slightly higher paddy yield (9.02 ton/ha) than with urea with the same N level (8.28 tons/ha).

Cotton: The use of digester effluent in the MOA tests produced slightly higher yields of seed cotton (3.97 tons/ha) than the heaviest application of chemical fertilizer (3.13 tons/ha).

Vegetables: In the MOA tests the yield of both broad beans and carrots were substantially higher with digester effluent than with chemical fertilizer containing comparable levels of nitrogen. However, cow dung gave the best results in the NRC's tests of both turnips and onions; fresh digester slurry produced more turnip roots than dried slurry or chemical fertilizer, but the production of onions with both fresh and dried slurry was only about half that with fresh dung.

Other presentations dealt with the economic significance of the use of digester effluent as fertilizer. Ward stressed that most digestion systems are economically viable only if the economic value of both the biogas and the effluent is fully utilized and credited in the economic analysis. Slurry utilization will affect the farmer's cash flow only if it replaces fertilizer and/or animal feed formerly purchased with money. Alaa El Din stated that in Egypt it is a considerable achievement to merely replace expensive chemical fertilizers, even without considering increased yields. However, the MOA research indicated that increased yields can provide a significant addition to the farmer's net income along with savings in fertilizer costs. Cost/benefit tables were calculated to show the net financial gain or loss in Egyptian pounds for each type of fertilizer tested; one US dollar equals about 1.2 Egyptian pounds (LE). Maximum net financial gains from the use of digester effluent rather than chemical fertilizer were calculated to be 681 LE/ha for maize, 342 LE/ha for wheat, 232 LE/ha for rice, 244 LE/ha for cotton, 227 LE/ha for broad beans, and 172 LE/ha for carrots.

3. Animal Feeding Benefits

Two papers described experience with the use of solids from the digester effluent as a supplement to the feed for livestock.

A paper prepared by Obias (Philippines) described a digestion system for a 500-sow hog farm which is based on experience at Maya Farms in the Philippines (p. 8). Digester effluent flows through shallow settling basins lined with grass cuttings which retain the solids while the liquid filters out to lagoons. About 740 kg of air dried digester solids would be recovered daily. The solids contain about 18% protein; about 5 to 10% of the dried solids is added to the feed mash for growing hogs at several farms in the Philippines. Each kg of dry digester solids saves about $.10 in feed costs; the total savings in feed costs at the 500-sow farm would be about $27,000 a year, which is nearly twice the energy savings derived from the digestion system.

Bellamy reported that solids removed by a vibrating screen from the digester effluent at a large pig farm in England are being used as a feed supplement for beef cattle. The inclusion of up to 10% of the air-dried digester solids in the cattle ration has not caused any palatability, health, or growth problems. The UK Ministry of

Agriculture found that Salmonella organisms, which were present in the slurry, were not detectable in the screened solids. Additional research is needed to determine the maximum percentage of solids which can be used, the length of time the animals can be kept on the diet, and the actual nutritional value of the digester solids for beef cattle.

4. Health Benefits

Smil (Canada) stated that the processing of animal and human wastes in biogas digesters could greatly improve local hygiene and eliminate or appreciably lower the frequency of several infectious diseases. Alaa El Din indicated that digester effluent used as fertilizer contains fewer pathogens and parasites than the traditionally prepared manures. Amaratunga (Sri Lanka) noted that hygienic toilet facilities are almost non-existent in rural areas in most developing countries and that integrated biogas systems in which toilets are connected to the digester could provide a simple and inexpensive means of partial treatment of sewage. Participants from India stated that about twenty community-scale biogas plants have such connected latrines.

However, most of the presentations dealing with health aspects of digestion systems indicated that there were a number of unresolved questions related to the health benefits of these systems. Several participants noted that the use of human wastes in digesters was not acceptable to many people in their countries. Prakasam (US) stressed that there are few clear-cut data to substantiate the widely-held belief in health benefits to the community through the widespread use of digestion of animal and human wastes. He pointed to the need for more research of the effect of biogas technology on the incidence of waterborne disease, the extent of the public health benefits which can be derived from biogas systems, and the extent of the public health risk to those working directly with the feedstocks and effluent of biogas plants.

Ward stated that, if a major purpose of a digester is to improve health by reducing the transmission of disease, longer retention times and/or higher operating temperatures are necessary to provide effective reduction of pathogens and parasites; these operating parameters are especially important if human wastes are to be used in the digester. Research at the NRC in Egypt indicates that the real retention times for many family-size digesters may be much shorter than it is generally assumed. Hamad reported that the use of tracer techniques showed that about 50% of the volume of both Chinese-type and Indian-type digesters is inactive and that the high degree of by-passing and short-circuiting of the slurry is very dangerous from the health and pollution standpoint. He indicated that this problem could be overcome in part by adding baffles which increase the flow path of the slurry and/or by using horizontal plug-flow digesters.

Four conference papers described research on the survival of pathogens and parasites during the anaerobic digestion of organic wastes which has been conducted at the National Research Center's Laboratory of Parasitology and Animal Disease, at the NRC Water Pollution Control Laboratory, and at Cairo University. In general, the studies showed that the survival rates varied widely depending on the pathogen or parameters of the digester.

Highlights of these papers are provided below:

Coliform: In tests at Fayum at 35°C, coliform rates decreased rapidly after 15 days. In digestion tests of cow dung, the coliform count decreased by about 98%. In tests of 2% night soil, the rate decreased by only 65%; however, when the digesters were fed with 5% night soil, the coliform count decreased by 94%. In tests of the digestion of cow dung at 37°C in the NRC water pollution control lab, 100% removal of faecal coliform was recorded when the influent contained 8% total solids, but the removal rate was much smaller at both lower and higher percentages of solids. The rate of coliform removal was also much smaller in field tests of digesters operating at considerably lower temperatures, and

coliform reduction during digestion was much more limited than the reduction during composting of the effluent beside the fermenter or in the field. At an Indian-type digester operating at the highest mid-summer temperatures, the density of the faecal coliform dropped from $2x10^8$ in the inlet sample to 8×10^3 in the composted sample. These and related results led the researchers to conclude that digestion should be followed by controlled composting.

Salmonellae: Experiments at the NRC parasitology lab indicated that, depending on parameters such as retention time and temperature, salmonellae are generally reduced about 90 to 99% by anaerobic digestion. At normal pH of about 6.9 the salmonellae survived only 14 days at 16°C but survived for 21 days at 28°C. There were indications in the field tests by the NRC water pollution laboratory of the repopulation by salmonellae in composts containing more than 20% moisture.

Clostridium: The NRC parasitology lab noted that clostridial organisms can resist anaerobic digestion and adverse conditions including complete dryness. The rate of destruction depended on the type of organism. C. welchii was the most affected by digestion; C. oedematiens was relatively resistant to digestion and both C. tetani and C. septicum were highly resistant.

Atypical Mycobacteria: Research at the NRC parasitology lab showed that anaerobic digestion causes the death of all atypical mycobacteria present; in lab digestion test these organisms survived for 28 days at 16°C but lived for only 14 days at 28°C. None of these organisms were isolated in the effluent from NRC digesters in three villages. These results confirm other research which indicated that anaerobic digestion causes the death of Mycobacterium tuberculosis. However, another paper from the same NRC laboratory suggests that digestion only inactivates about 90% of the mycobacteria, and that the organisms may persist for long periods in drying sludge.

Eschericha coli. Enteropathogenic E. coli was detected by the NRC water pollution lab in the digester influent and effluent and in the composted sludge of the NRC village digesters. These results confirmed the risks associated with the land application of the composted effluent, if composting is not performed correctly.

Streptococci: In the tests by the NRC water pollution lab of samples from an Indian-type digester in mid-summer, the density of faecal streptococci dropped from 2×10^8 in the inlet samples to only 2×10^2 in samples of composted slurry. The faecal streptococci were completely removed in tests of the digestion of cow dung mixed with 10% or more water hyacinths.

Ascaris eggs: The analysis by the NRC parasitology lab of samples from village digesters showed considerable variation from village to village. At Omar Makran 33% of the inlet samples contained Ascaris eggs, but the eggs were found in only 13% of the outlet samples. Half of both the inlet and outlet samples from El Manawat contained the eggs, while there were no eggs in any samples from the heated digester at Shubra Kass. No eggs were found in the composted effluent at Omar Makrum and only 25% of the samples from such a pile at El Manawat contained the eggs. The researcher noted other studies which indicate that variations in the distribution of the Ascaris eggs may be due to variations in temperature; one Chinese publication indicates that the eggs survive longer at lower winter temperatures.

Eimeria oocysts: In the tests by the NRC parasitology lab the percentage of outlet samples containing the oocysts (88%) was only slightly lower than in the inlet samples (80%) at Omark Makrum. At El Manawat the percentage of samples from the inlet with parasites was 62.5%, while 50% of the outlet samples contained the oocysts. Half of both the inlet and outlet samples contained the parasites at Shubra Kass. However, the percentage of samples drawn from heaps of composted effluent which contained the parasites was much smaller in all three villages (25% in Omar Makrum 12.5% in El Manawat, and none at Shubra Kass.)

PART SIX:
THE DIFFUSION OF BIOGAS SYSTEMS

Presentations and discussions at the conference dealt with a number of factors which influence the extent of the diffusion of biogas technology in developing countries.

1. Cost Effectiveness of Present Systems

There appeared to be agreement among the conference participants that the relatively high capital costs of family-sized biogas plants were the most important reason for the limited cost effectiveness of most plants and thus a major limitation on the diffusion of biogas systems. Most of the papers presented at the conference reflected the extensive efforts which are being made around the world to develop more productive and cost effective biogas systems.

The effect of the investment cost of digesters on the profitability of biogas systems was indicated in a study reported by Li (China). It examined the total economic benefits from the utilization of both biogas and effluent in two counties in China. In Chongquing county, where the average digester cost was rather low, the total annual economic benefit to the county was 38% of the total investment in biogas plants in the county and the investment recovery period was estimated at 2.6 years. In Haian county, where the average cost of digesters was twice that in Chongquing, the annual economic benefit was only 24% of the total investment cost and the investment recovery period was about four years. Another study in China showed that the investment recovery period was between 7 and 8 years for the digesters built by three production teams and that 25 years would be needed to recover the cost of very expensive units built by another production team. Li noted that these studies show the need to reduce the capital and operating costs of biogas plants in order to increase the annual net profit from the operation of the units.

Moulik (India) commented that the results of cost/benefit analysis on biogas systems are very dependent on the accuracy of the assumptions made concerning the physical quantities and monetary values of both inputs (costs) and outputs (benefits). El Halwagi (Egypt) noted that the tangible outputs of biogas systems - biogas and digested effluent - are difficult to value in monetary terms since they are not commodities which are usually traded. Moulik cited other factors complicating cost/benefit analysis including the lack of standardized data on the quality and quantity of inputs and outputs, the uncertain economic life of biogas plants, and confusion arising from the use of domestic market prices, subsidized government prices, world prices, and/or presumably inflated future prices. Moreover, it is very difficult to establish monetary values for some important benefits of a biogas system including the health benefits, the convenience and comfort of cooking, and the prestige value of the system.

In view of these difficulties, some of the cost/benefit analyses have considered only those factors which have a demonstrable effect on the owner's cash flow. Moulik noted that a number of these studies have indicated that the monetary benefits to the private owner of the biogas plant were less than the costs incurred. However, the same analyses usually indicate that if all of the indirect benefits could be quantified, the total benefits would outweigh costs. Moreover, almost all of the studies indicated that, if all the macroeconomic and long-term societal benefits are fully considered, a biogas program turns out to be a viable national investment.

Some participants expressed the opinion that large-scale efforts to disseminate biogas technology in developing cuntries should not be carried out until better and cheaper biogas plants have been developed. However, extended discussion in a plenary session indicated that the majority of the participants felt that the technical and cost effectiveness of present biogas systems are sufficiently high to warrant maximum dissemination efforts without waiting for further improvements.

Several participants expressed the view that systems which meet user needs and avoid social and cultural problems can only be developed by trial and error within programs for the wider dissemination of biogas technology in each country.

2. National Infrastructure for Biogas Diffusion

Both Stuckey and El Halwagi stressed in the opening session that an effective organizational infrastructure was essential for the diffusion of biogas systems. Stuckey pointed to the need for strong governmental interest and backing and an effective infrastructure to coordinate diffusion activities, provide technical assistance, and allocate resources. El Halwagi felt that the means of optimizing the exploitation of biogas technology were all linked in one way or another to an effective infrastructure.

Two discussion sessions chaired by P. Weatherly (AID Bioenergy Project) revealed divergent opinions on the best type of organizational structure for national biogas program. El Halwagi and others favored an institutional apparatus whose primary or even sole activity is the diffusion of biogas technology. This view was supported by most participants in a smaller discussion group chaired by Umana (Costa Rica); the group felt that a specific biogas organization is needed to provide centralized policy and coordinated R & D for the biogas program and that these functions would be less effective within a larger organization such as a Ministry of Agriculture. It was noted, however, that a considerable degree of decentralization may be desirable in the dissemination efforts. Others felt that it was unrealistic and/or undesirable to attempt to create a separate biogas agency and that the goal should be maximum coordination and teamwork among all of the relevant agencies.

Participants from India outlined the "multi-agency, multi-model" system for biogas dissemination now being used in their country; it includes coordination since 1982 by the Department of Non-Conventional Energy Sources and implementation by a separate biogas agency in each state, other national and state agencies, and non-governmetal organizations. Several participants indicated that the effectiveness of the coordination and cooperation among the participating agencies is more important than the details of the organizational structure. El Halwagi's conference summary emphasized that the management of a multi-insititution, multi-purpose, and multi-disciplinary biogas effort requires a very effective organization and skilled managers.

The important role of private sector organizations was also recognized. Singh (India) described the biogas training and other activities carried out by Action for Food Production (AFPRO) and other non-governmental organizations in support of the national biogas program in India. DuMouchel (Thailand) indicated that biogas dissemination activities could be an important part of the rural development efforts of voluntary organizations and foundations. A discussion group on commercial and industrial scale biogas projects agreed that the promotion of such projects required effective cooperation between private sector firms and governmental biogas agencies.

3. Training

Many presentations stressed the crucial importance of effective training programs in the diffusion of biogas technology.

El Halwagi noted that a strong training program on the construction and installation of biogas plants has been a key element in the biogas dissemination effort in China. Singh reported that AFPRO operates 50 biogas training and extension centers in India and is training about 500 masons annually in the construction of biogas plants. Caceres (Latin American Energy Organization) described a series of the extensive practical training courses which have been provided to participants from the ten countries taking part in the OLADE biogas program. The report by Ingram (ICAITI) indicated that ICAITI's biogas dissemination program has included the training of 62 persons in the construction and operation of digesters. C. Ofori (FAO)

stated that FAO has sponsored three biogas training courses at the Chengdu training center in China and is also funding the participation of biogas experts from China and other developing countries in training programs organized by various national biogas agencies.

Some of these courses and seminars have also provided a second type of biogas training needed by persons engaged in biogas extension activities; such persons are involved with the promotion of biogas technology among farmers, detecting potential users, assisting with construction of plants, and advising the farmers on plant operation.

Amaratunga (Sri Lanka) stated that one-week training courses on biogas systems have been provided for agricultural extension workers in Sri Lanka under the Department of Agriculture's in-service staff training program; in addition, a regular academic course on biogas technology is offered to senior engineering students at the University of Peradeniya. More than 50 persons from the U.S. insular territories and South Pacific Island nations attended two biogas workshops in 1984 in the Commonwealth of the Northern Mariana Islands.

The third type of training need recognized at the conference involves the provision of information and training directly to the users of biogas plants. Caceres cited the lack of sufficient user training as a major reason for technical problems with many of the biogas plants built under the OLADE biogas program. Ingram indicated has ICAITI has recognized the need for training of users on the operation and maintenance of biogas plants, and Singh noted that AFPRO will be giving great attention in the future to the direct training of plant users.

4. International Information Exchange and Technology Transfer

There seemed to be agreement among the participants that the rapid development of more effective biogas systems requires more extensive and effective international exchange of experience on biogas technology. Sasse (Germany) commented that there has been considerable talk about sharing information, but insufficient time has been spent in the direct and useful exchange of experience. El Halwagi's conference summary indicated a consensus that the rate of diffusion of biogas technology is now limited more by inadequate dissemination of information which is already available than by the state of develoment of biogas technology.

Ofori reviewed FAO's efforts to develop regional biogas interchange networks. Binger (Jamaica) stated that the emerging Bioenergy User Network hopes to sponsor interchange among field-oriented people on various phases of bioenergy. A discussion group on commercial and industrial scale biogas plants pointed to the need for a system for exchanging information on the design and operation of such plans between developing countries.

The need for more effective collaboration between biogas experts of developing and developed countries was also noted. Edelman (Switzerland) stressed that such collaboration is usually fruitful only if the expert from a developed country is very familiar with conditions in the developing country. P. Pluschke (German Agency for Technical Cooperation) noted that the German Biogas Extension Service sends multi-disciplinary teams to work for extended periods with counterparts in selected countries.

Due to time limitations, there were only limited comments on the means of organizing expanded international interchange on biogas technology. Stuckey called for the establishment of a "focus" institute in each country which would collect information on biogas developments in the country and present this information at network meetings. El Halwagi suggested a central organization or clearing house to collect information on biogas and other energy options, working with a number of regional subcenters for information collection and regional coordination of research activities.

EDITOR'S SUMMARY AND CONCLUSIONS

The following are a number of conslusions derived by the Editor of this Report from his participation in the biogas conference in Cairo:

1. Despite many unresolved technical and economic problems, biogas technology has continued to evolve and spread in developing countries in the 1980's. Several national development assistance agencies and international organizations are actively assisting national institutions with biogas projects and programs.

2. The great majority of the digesters built in developing countries have been variations on either the Chinese fixed-dome digester or the Indian plant with floating steel gasholder. A number of important modifications on these basic designs have been made in various countries, but experience with these modified designs has been scattered and has not been widely shared with other countries or effectively evaluated. While a considerable number of other types of biogas plants have also been built in developing countries, the number of units of any one type has been small and the international exchange of experience with these units is also very limited.

3. There is inadequate understanding of and consensus on the interrelated effects of various operating parameters (especially solids concentrations, loading rates, retention times, substrate mixing, and digester temperatures) on the performance of digester. The operating conditions in many digesters have been determined by various external factors rather than through careful efforts to optimize digester performance. The need for effective means of optimizing digester temperature is rather widely recognized, but experience in developing countries with various digester heating techniques remains rather limited and inadequately shared.

4. Most of the biogas experience in developing countries is concentrated on the use of dilute manure slurries; experience with other biodegradable materials (including crop residues, urban residues, and agroindustrial residues) is growing but still limited to a few countries.

5. Although the benefits of biogas as a cooking fuel are widely appreciated, there is much less awareness of and information on other potential uses of the gas including the production of mechanical and electrical power. Most published information describes family biogas plants producing cooking gas. There has been very limited international exchange of information on systems in which the gas is used in an engine or generating set.

6. Both the health benefits and the agricultural benefits of the use of the digester effluent as fertilizer seem impressive, compared to the use of undigested manure. However, these benefits have been carefully studied in only a few countries and the available studies show a wide range of results depending on operating parameters and external conditions.

6. The diffusion of biogas technology requires an effective national infrastructure to coordinate the activities of participating agencies, provide technical information and assistance, allocate resources, and conduct several types of training programs. However, the most important factors limiting the diffusion of biogas systems at present appear to be the high cost and rather low productivity of most of the digesters used in developing countries. These digester problems are compounded by the limitations outlined above related to feedstocks, operating parameters, gas utilization, and effluent utilization.

7. The development of more productive and less expensive biogas systems requires a much wider and more intensive international exchange of experience on a number of specific aspects of biogas technology. The biogas conference in Cairo facilitated the exchange of a great body of biogas information among conference participants. However, the discussions at Cairo indicated clearly the need for a wider range of occasions and techniques for the in-depth exchange of information on biogas systems in developing countries.