VOLUME I, NUMBER 1, JULY 1996

ENGINEERING JOURNAL

The Official Journal of the
College of Engineering
Central Philippine University

1936-1996

COLLEGE OF ENGINEERING
CENTRAL PHILIPPINE UNIVERSITY
Iloilo City, Philippines

Published by the College of Engineering, CPU

Printed by Makinaugalingon Press

ENGINEERING JOURNAL

Published Annually by the College of Engineering
Central Philippine University, Iloilo City, Philippines

The CPU ENGINEERING JOURNAL is published annually by the College of Engineering of Central Philippine University. The Journal is a report of the results of completed researches of the Engineering faculty, alumni and other extension units of the College. The papers submitted for publication should exhibit originality, reflect quality and quantitative research, and provide important new information to help address important issues in the community. These may include state-of-the art articles, theoretical and applied researches related to Engineering.

Manuscripts must be submitted in the style and format illustrated in the articles published in this issue. Papers are normally limited to 15 pages including figures, diagrams and tables. An abstract (not exceeding 200 words) is required at the beginning of each paper. All articles should follow bibliographic conventions as listed in the Chicago Manual of Style.

Three hard copies of the article written in double space are required. Articles submitted will go through a review process. In all cases, however, the Editorial Board reserves the right to edit the paper in consultation with the authors concerned to assure clarity. After a manuscript is accepted for publication, the author submits a computer disk (5.25" or 3.5" diskette) containing the revised version of the paper.

The views expressed in the papers by the authors do not necessarily reflect the view of the editors of the Journal. Letters to the editor regarding the papers published are welcome to encourage an interchange of ideas within the CPU academic community, other engineering institutions and industry.

All manuscripts for publication should be sent to:

The Editor-in-Chief
CPU Engineering Journal
College of Engineering
Central Philippine University
Jaro, Iloilo City 5000

TUNING OF SPEED-GOVERNING SYSTEM FOR KALAYAAN PUMPED STORAGE POWER PLANT

CIRILO C. CALIBJO
Electrical Engineering Department, Central Philippine University

Abstract---*Changes in system frequency are caused by any imbalance between load and generation. To control these, a speed governor is usually provided. The change in frequency may be either stable or unstable depending on the values of the parameters of the plant and governor. This paper describes a simple analytical procedure of tuning electro-hydraulic P.I.D. governors for the units of Kalayaan Pumped Storage Power Plant. Mathematical analysis is carried out using MATLAB simulation software, while validation through time simulation is performed using Power System Simulator/ Engineering (PSS/ E). Optimum gain settings were found both during isolated and grid operations. Although actual plant testing was not possible, the result of the study is seen as an improvement from the usual trial-and-error approach which is currently being practiced.*

INTRODUCTION

Generating units operating synchronously in parallel in a power system must have a means of controlling their speed by automatically adjusting their mechanical power to maintain balance between load and generation. Such is the function of a speed-governing system or speed governors.

Synchronous operation implies a common electrical speed or frequency among the generators and the rest of the system. Imbalances between load and generation are reflected by proportionate changes in system frequency. A frequency below nominal value is a sign that the load exceeds the generation while a frequency above nominal indicates otherwise. Using speed or frequency as input, speed-governors respond by adjusting the power output of the generating units to restore the balance and correct the frequency errors.

System components such as steam turbines are sensitive to frequency changes due to severe vibrations which cause cumulative metal fatigue and loss-of-life. To minimize exposure to below nominal frequency, especially during sudden loss of generation, underfrequency relays are installed on feeders to automatically drop customer loads. Although this has been a long accepted practice, it results in service interruption when frequency is poorly regulated.

Among the different types of generating plants, the hydroelectric units are very suitable for frequency regulation primarily due to their simple energy conversion process which are relatively easier to control. Modern hydro units, like those of the Kalayaan Pumped Storage Power Plant (KPSPP) of the National Power Corporation, are equipped with electro-hydraulic P.I.D. (proportional, integral and derivative) speed-governors which greatly facilitate tuning for improvement of response.

Early endeavors have been made with regard to governor tuning for speed control of hydro-generators. Attempts to establish a generalized guideline for the selection of control parameters were also considered. The work of Hovey [1] and Chaudry [2] investigated the stability of the hydraulic turbine-generating unit controlled by temporary droop governors. Thone and Hill [3] studied the stability region of a hydraulic turbine generating unit having a P.I.D governor. They showed the stability boundaries as a function of proportional and integral gains but no reference is made to the derivative gain. Dhaliwal and Wichert [4] analyzed the effect of derivative gain on the stability of a single machine supplying an isolated load. In the aforementioned, no attempts were made to define the stability boundary, until later, Hagihara, et al [5] expanded the works of Hovey and Chaudry to show the stability boundaries of a hydraulic turbine generating unit having a P.I.D. governor. Unfortunately, the above investigators have used simplified models for the turbine-penstock and water column.

Sanathanan [6] presented a frequency domain method to determine the optimum values for the parameters of a P.I.D. governor. The method readily handles detailed models of turbine-penstock, gate dynamics and other system dynamics.

The problem of tuning the speed-governing system of the KPSPP was considered in the SwedPower Report [10]. The unit test result showed that the unit has good automatic frequency regulating capacity but the P.I.D. governor parameters need to be adjusted in order to be coordinated with other units operating on free governor.

The purpose of this report is to introduce a simple analytical procedure of tuning P.I.D. speed governors for hydro units for optimum response during isolated and grid operations with due consideration for control stability. Thus, this paper presents a root locus and time domain method based on Guillemin-Truxal Design approach in tuning the P.I.D. governor of the KPSPP. There are two main advantages of the method namely, simple computations required and the designer can prespecify a speed response for load change.

ANALYTICAL INVESTIGATION

The analytical investigation, in an attempt to tune the speed-governing system for hydro-turbines, includes adequate representation of the speed governor, the gate dynamics, the hydro-turbine and water column, and the generator.

An examination of this problem shows that, for small disturbance analysis, a reduced-order model for the system is adequate in determining the response after the disturbance has occurred.

The reduced block diagram of the speed-governor is shown in Fig. 1.

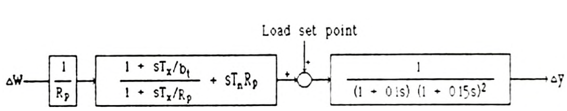

Figure 1. Reduced P.I.D. Controller Block Diagram

and a more realistic hydraulic system model:

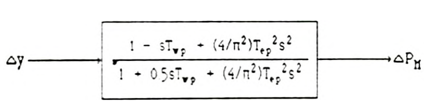

Figure 2. Hydraulic System Block Diagram Relating Turbine Mechanical Power Output and Gate Position Change

The generator and load model is shown in Fig. 3.

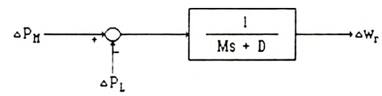

Figure 3. Reduced Rotating Mass-Load Block Diagram

The Hydro-unit Block Diagram

The complete speed control of the hydro unit is now represented by the block diagram as shown in Fig. 4.

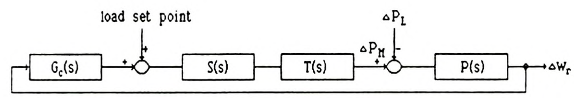

Figure 4. Block Diagram of Speed-Governing System

The component transfer functions derived from the model are defined by the following equations:

$$G_c(s) = \frac{T_n s^2 + \dfrac{T_n R_p + T_x / b_t}{T_x} s + \dfrac{1}{T_x}}{s + \dfrac{R_p}{T_x}} \tag{1}$$

$$S(s) = \frac{1}{(1-0.1s)(1+0.15s)^2} \tag{2}$$

$$T(s) = \frac{1-1.0304s+0.4601s^2}{1+0.5152s+0.4601s^2} \tag{3}$$

$$P(s) = \frac{1}{9.86s} \tag{4}$$

For frequency control studies, the block diagram can be reduced into the form shown in Fig. 5.

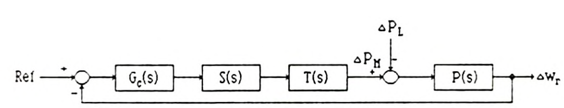

Figure 5. Reduced Hydro Unit Block Diagram

Let a reference model M(s) be specified as in Fig. 6.

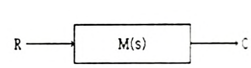

Figure 6. Reference Model

The central idea involved in this method consists of finding $G'_c(s)$ such that the time response of the closed loop transfer function, C/R, matches that of M(s). For this the required $G'_c(s)$ must satisfy:

$$G'_c(s) = \frac{M(s)}{[1 - M(s)]S(s)T(s)P(s)} \quad (5)$$

This is known as the synthesis equation by Guillemin-Truxal Design approach.

For controller design purposes, it is found that the low order approximation of the ideal $G'_c(s)$ which is accurate in the critical low frequency band, is sufficient. The transfer function of $G'_c(s)$ can be generated readily from eq. (5) for any elaborate equation for S(s), T(s) and P(s). From this information, a low order transfer function $G'_c(s)$ is synthesized.

Since for a step change in ΔP_L, see Fig. 5, the steady state value of Δw_r must be zero, it is clear that $G'_c(s)$ must contain a pole at the origin.

Selection of the Reference Model

A selection procedure is carried out considering the units of Kalayaan Pumped Storage Power System parameters. From eq. (3), it is clear that T(s) is a non-minimum phase transfer function. Therefore, it is necessary that M(s) must retain exactly the same right-half-plane zeros as those of T(s) [13]. If not, $G'_c(s)$ will turn out to be unstable.

The pole locations for M(s) are somewhat arbitrary. However, M(s) must have at least four poles. This will become clear as the procedure continues. Using the **0.707** damping ratio as a design criterion, let two pole pairs of M(s) be chosen as:

$\mathbf{s_{1,2} = -0.3 \pm j0.3; \; s_{3,4} = -1.0 \pm j1.0}$

This leads to the following reference model:

$$M(s) = \frac{(1 - 1.0304s + 0.4601s^2)(1 + as)}{(1 + 4.333s + 9.389s^2 + 7.222s^3 + 2.778s^4)} \quad (6)$$

The additional term, (1 + as), in eq. (6) is chosen with an appropriate value for 'a' such that the coefficients of s^0 and s^1 are the same for the numerator and the denominator of M(s). This is to ensure that the implied close loop system corresponding to M(s) will have two poles at the origin (one for P(s) and the other for the controller). Hence, **(a - 1.0304) = 4.333** and therefore, **a = 5.3634**. Note that if a load regulation factor is included in P(s), the additional term will not be necessary.

Thus, the numerator of M(s) must have a degree of three. Therefore, the denominator of M(s) must at least be of degree four, to make M(s) appear as a proper transfer function.

To simulate step response, Fig. 6 is transformed into Fig. 7 in which:

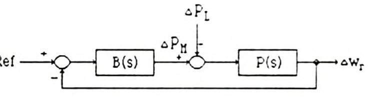

Figure 7. Modified Reference Model

$$B(s) = \frac{M(s)}{[1 - M(s)]P(s)} \quad (7)$$

Using eq's. (6) and (7):

$$B(s) = \frac{(1 - 1.0304s + 0.4601s^2)(1 + 5.3634s)}{s(1.4661 + 0.4823s + 0.2817s^2)} \quad (8)$$

Figure 8 gives the response of the reference model for a 10% load increase.

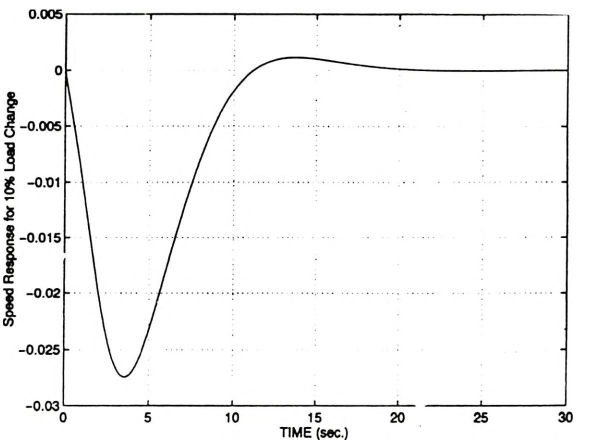

Figure 8. Speed Response of the Reference Model for a 10 Percent Increase in Load

The transfer function of $G'_c(s)$ of the ideal controller can be determined by means of eq's. (5) and (6). This transfer function was matched using a simple expression of the equivalent P.I.D. controller, eq. (1).

The value of Rp meanwhile is set to zero. Note that from eq. (1), $1/T_x$ is the limit of $G_c(s)$ using the final value theorem, and it is evaluated readily using eq's. (1) and (5). Therefore, T_x is constrained to this value while obtaining the optimum values of T_x/b_t and T_n. From eq. (5), applying the final value theorem, $G'_c(s)$ approaches 0.6821. Since the controllers of KPSPP units have discrete set points for parameter adjustment, the best value that matches this is $T_x = 1.65$ and the integral gain is forced to this value. Optimization is carried out using the mean square error of the time response between $G_c(s)$ and $G_c'(s)$. This is carried out using discrete values of T_x/b_t and T_n set points of the Kalayaan controller model.

For the case presented above, the optimum governor parameters setting are:

$\mathbf{T_x = 1.65;\ \ T_n = 1.7;\ \ T_x/b_t = 5.3}$

Using the above parameters for the P.I.D. controller, the hydro-turbine unit has been simulated with S(s), T(s), and P(s) defined by eq's. (2), (3) and (4), respectively. The speed responses for 10% load increase are shown in Fig. 9. The responses do match the prespecified response quite well. Figure 9 also shows the comparison of the speed responses using the gain values from the MATLAB simulation and the default setting obtained from the National Power Corporation (NAPOCOR) considering the effect of speed droop. The figure shows that an improved damping and settling time are achieved using the gains obtained by this technique.

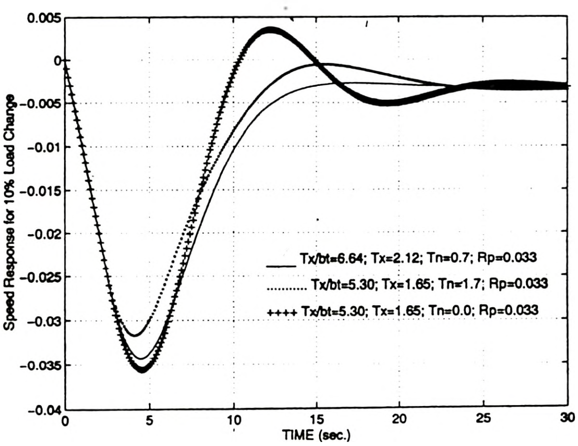

Figure 9. Comparison of Speed Responses with Speed Droop

PSS/E VALIDATION

The result of the analytical investigation is verified using the PSS/E software by simulating both the island and synchronous operations of KPSPP. The network data used for the study has been derived from the NAPOCOR in the form of PSS/E raw data.

Isolated Mode of Operation

The governor data is first verified by simulating the response of the individual units in isolation. This test simulates the response of the governing loops of all units, in isolation, to a step change in load. The KPSPP unit initial condition is set to 60% of the MW rating of one unit and a step change of 10% is applied.

Three different sets of P.I.D. parameter settings

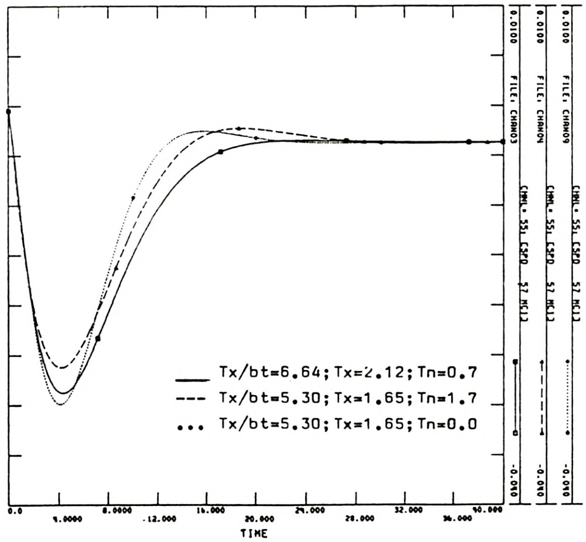

Figure 10. Comparison of Speed Responses

are used in the case of KPSPP. The two sets are the result of the analytical investigation while the other set is obtained from the NAPOCOR performance specifications. Figure 10 shows that the result of the analytical investigation is in close coordination with the result obtained from the PSS/E simulation.

With the governor parameters set at $T_x/b_t = 5.30$, $T_x = 1.65$ and $T_n = 1.7$, a 10% load increase on this unit showed that the speed dropped to a certain minimum peak and then settled down without oscillation to a value just below nominal, as determined by the speed droop of 3.33 percent. Also the improvement in the undershoot is very noticeable.

Synchronized Mode of Operation

To determine the response of the speed governor when the units are connected for synchronous operation, simulation is performed for a case where frequency is controlled by a combination of seven (7) oil thermal units and one (1) hydro unit, the KPSPP. The mode of operation is to consider the system in normal synchronous operation and suddenly trip off one generating plant connected in the system. A total of 36 generating pants are considered connected in the simulated system. This test assumed that there is enough operating reserve and that it is capable of taking care of the generator tripping as applied in this test.

The same three sets of P.I.D. parameter settings are used for the electro-hydraulic governor of KPSPP unit while maintaining the same conditions for other plants participating in the frequency control. Figure 11 shows the speed responses of KPSPP for three cases considered. This figure reveals that an optimum performance is achieved for a condition where the P.I.D. parameters setting is,

$$T_x/b_t = 5.30; \quad T_x = 1.65; \quad T_n = 0$$

With the parameters tuned to these values, a faster and smoother response is achieved.

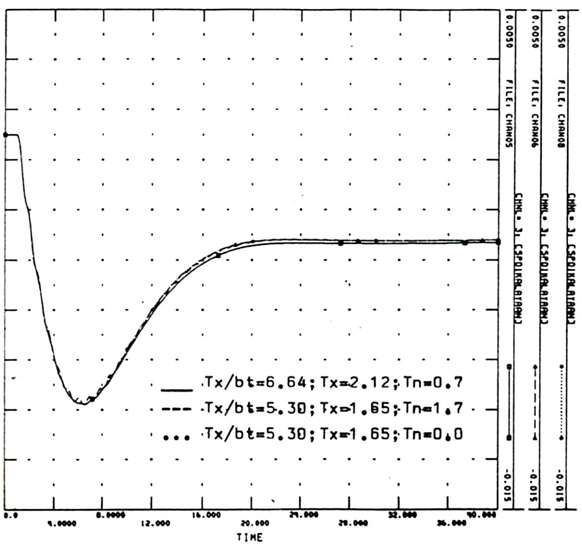

Figure 11. Comparison of Speed Responses

Figure 12 shows the electrical power response from the generator. The fluctuations in the first seconds are not caused by the governor system but are due to the oscillations between different generators. This can be found by comparing the electrical power response of Fig. 12 to the mechanical power response of Fig. 13. A somewhat less obvious but nevertheless perverse characteristic of the derivative action of the P.I.D. governor is its tendency to accentuate distortion of the gate

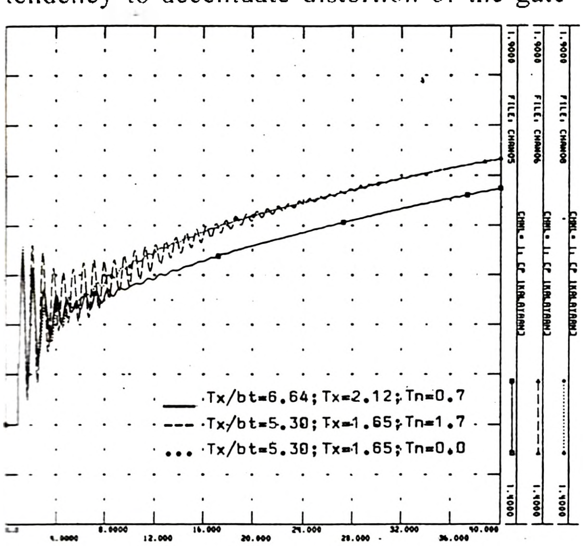

Figure 12. Electrical Power Output

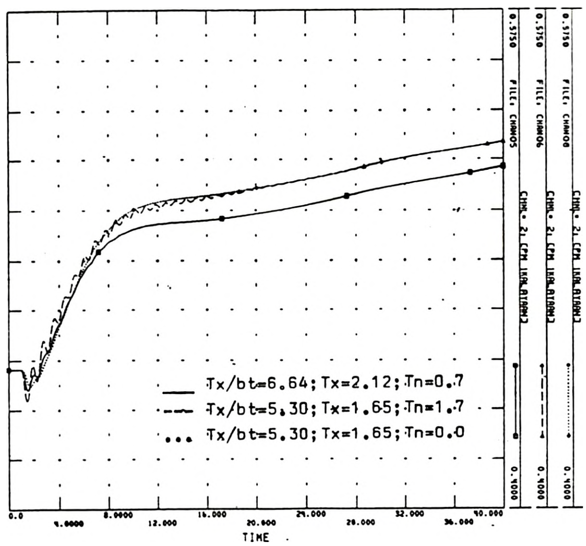

Figure 13. Mechanical Power Output

movement, Fig. 13.

From Fig. 11, the period of speed transient of the KPSPP under synchronous operation lies between the respective periods of the speed transients of the individual units on isolated basis and is appropriately damped. Although the speed transient of the KPSPP under the synchronous operation is over in approximately 18 seconds, Fig. 13 shows that there is a continuous secondary readjustment of gate position. Following application of generator tripping, the faster of the units participating in the frequency control picks up the greater share of the generation change. Then, after the speed has been corrected, the units gradually shift load until it is divided according to their droop characteristics.

CONCLUSION AND RECOMMENDATIONS

The following important results and observations are listed in conjunction with the tuning of the speed-governing system of KPSPP for both isolated and synchronized operating modes.

*Frequency excursion can be easily controlled if frequency control is distributed to a large number of units with free governor operation.

*The step response test for the KPSPP reveals that a much improved performance is achieved if the governor parameters are tuned to $T_x/b_t = 5.30$, $T_x = 1.65$ and $T_n = 1.7$. This is verified by both the analytical investigation and the PSS/E software simulation.

*The stability of KPSPP under island operation is enhanced by appropriate derivative gain.

*Under synchronous operation, there is no need for the derivative function on the KPSPP governor unit. Its presence accentuates the noise due to interaction among the different generators connected in the system. The optimum performance is achieved when $T_x/b_t = 5.3$, $T_x = 1.65$ and $T_n = 0$.

*The above recommended setting allows the units of KPSPP to respond faster and take a greater proportion of the generation change.

*By eliminating the derivative function, a calmer regulation is obtained and thereby less maintenance will be required.

*A governor parameter setting for good speed regulation under an isolated condition also yields good regulation for system operation under normal condition after the derivative function is eliminated.

*Though actual plant testing was not possible, the result of the study is seen as an improvement from the usual trial-and-error approach which is currently being practiced.

ACKNOWLEDGMENT

The author expresses his heartfelt thanks to his adviser, Prof. Artemio P. Magabo, for his untiring guidance and patience. Engr. Mario R. Pangilinan, Manager, Luzon Transmission Planning Division of the National Power Corporation (NAPOCOR, Quezon City), as consultant has been a great help.

NOMENCLATURE

$1/b_t$	Coefficient of the proportional action
D	Load damping constant
$G_c(s)$	P.I.D. controller transfer function
M	Angular momentum of the machine
P(s)	Turbo-generator transfer function
ΔP_L	Change in electrical power
ΔP_M	Change in mechanical power
R_p	Permanent speed droop
S(s)	Actuator-servomotor transfer function
T(s)	Turbine-penstock transfer function
T_n	Time constant of the derivative action
T_v	Water starting time $= Z_p T_{ep}$
T_x	Time constant of the integral action
Δw	Deviation from the nominal frequency
Δw_r	Change in rotor frequency
Δy	Deviation from the servomotor stroke

REFERENCES

Hovey, L.M., "Optimum Adjustment of Governors in Hydro Generating Stations," The Engineering Journal, Vol. 43, Nov. 11, 1960.

Chaudry, M.H., "Governing Stability of a Hydro-Electric Power Plant," Water power and Dam Const., pp. 131-136, April 1970.

Thone, D.H. and Hill, E.F., "Extensions of Stability Boundaries of a Hydraulic Turbine Generating Unit," IEEE Trans., Vol.PAS-94, pp.1401-1409, July/August 1975.

Dhaliwal, N.S. and Wichert, H.E., "Analysis of P.I.D. Governors in Multimachine System," IEEE Trans., Vol.PAS-97, March/April 1978.

Hagihara, S., Yokohata, H., Goda, K., Isobe, K., "Stability of Hydraulic Turbine Generating Unit Controlled by P.I.D. Governor," IEEE Trans., Vol.PAS-98, No. 6, pp. 2294-2298, Nov/Dec. 1979.

Sanathanan, C.K., "A frequency Domain Method For Tuning Hydro Governors," IEEE Trans., Vol.EC-3, No. 1, pp. 14-17, March 1988.

Wozniak, L. and Blitz, D.J., "Load-Level-Sensitive Governor Gains for Speed Control of Hydrogenerators," Vol.EC-3, No.1, pp. 78-84, March 1988.

Orelind, G., Wozniak, L., Medanic, J., Whittemore T., "Optimal P.I.D. Gain Schedule for Hydrogenerators-Design and Application," IEEE Trans., Vol.EC-4, No. 3, pp. 300-307, Sept. 1988.

SwedPower, "Luzon Power System Improvement-Stage III, Part III-Frequency Regulation," National Power Corporation, May 1993.

Dandeno, P.L., Kundur, P., Bayne, J.P., "Hydraulic Unit Dynamic Performance Under Normal and Islanding Conditions-Analysis and Validation," IEEE Trans., Vol.PAS-97, No. 6, pp. 2134-2143, Nov/Dec. 1978.

Schlief, F.R. and Wilbor, A.B., "The Coordination of Hydraulic Turbine Governors for Power System Operation," IEEE Trans., Vol. PAS-85, No. 7, pp. 750-758, July 1966.

Kundur, P., Power System Stability and Control, McGraw-Hill, New York, 1994.

D'Azzo, J.J. and Houpis, C.H., Linear Control System Analysis and Design: Conventional and Modern, 3rd ed., McGraw-Hill, New York, 1988.

Wozniak, L., "A Graphical Approach to Hydrogenerator Governor Tuning," IEEE Trans., Vol.EC-5, No. 3, pp. 417-421, Sept. 1990.

DEVELOPMENT OF A LOW-COST TENSION-COMPRESSION EQUIPMENT

WALDEN S. RIO
Dean, College of Engineering, Central Philippine University

Abstract---*The cost of a typical tension-compression equipment is too high so that only a few Civil Engineering (CE) Schools can afford to purchase it. There is, therefore, a need to design and fabricate a low-cost tension compression equipment which CE schools can afford to buy. An applied research project was undertaken to find ways to make such a type of equipment available. The study resulted in the fabrication of a low-cost equipment that could be used for small size tension-compression testing. The results of the testing were not as accurate compared with that of the Universal Testing Machine. Nevertheless, the equipment serves the purpose of letting the students understand the process of testing and provides a solution to the need of Engineering Schools for an affordable tension-compression equipment for their Materials Testing Laboratory.*

INTRODUCTION

In 1985, the Technical Panel for Engineering Education (TPEE) required all engineering schools to comply with the minimum standards for equipment needed in the various engineering laboratories. It was found however that a number of the equipment specified were either useless or not applicable to the practice of civil engineering. An additional problem presented was to identify the people who prepared the minimum equipment standard.

A national conference participated in by representatives from selected civil engineering schools all over the Philippines was held in 1989 to rectify these problems. The purpose of the conference was to list down laboratory exercises that can be undertaken and the corresponding equipment needed for each laboratory exercise.

When the list of laboratory exercises was prepared and the type and number of equipment was specified, the cost of obtaining the equipment was considered. It was found that there is a need to cut down the costs of the equipment. The main reason for this was the fact that majority of the engineering schools could not comply with the minimum number of equipment required by the TPEE Standards. Complying with these standards means spending a sizable amount for the purchase of the equipment. To soften the impact of cost, the number and type of equipment had to be kept to the minimum as required.

In another conference in 1989 the minimum standards for equipment was revised resulting in an increase in the number of equipment. There was therefore a need to introduce a low-cost compression machine. The need was brought about by the fact that testing a reinforcing bar is a very important component in Material Testing.

PROBLEM

The need of undertaking an applied research to design and fabricate low-cost tension-compression equipment had to be answered. The design of the equipment was based on two objectives. First, the cost of fabricating the equipment had to be kept to a minimum. Second, if possible part of the fabricated equipment be made available as a required minimum standard equipment for civil engineering schools. In upgrading it to a tension-compression equipment, the process would be simple and the cost be minimum.

It is an accepted fact that if cost is kept at a minimum, the accuracy of the equipment would not be high. Low accuracy in this case was not much of importance because the developed equipment will be used for instructional purposes only. What is important is for the students to learn the rudiments of material testing using the testing-compression equipment. Hence, the Center for Civil Engineering of the CPU College of Engineering decided to undertake a research on how the equipment would be designed to address the problem presented.

WORK UNDERTAKEN

In order to answer the need for a low-cost Tension-Compression equipment, a survey was undertaken based on the TPEE minimum standards. The purpose of the survey was to take a look at existing minimum standard equipment used in the Material Testing laboratory. A similar survey was also undertaken for equipment used in the Soil Mechanics Laboratory.

The result of the survey in the Material Testing Laboratory showed that the only equipment suited for the purpose was the compression machine. It was found that the cost of a manually operated compression machine of fifty ton capacity would cost around a hundred thousand pesos. A mechanical compression machine would cost more than a hundred fifty thousand pesos. If this equipment is to be converted into a tension compression equipment, the cost would go up to more than two hundred fifty thousand pesos. Since cost was the prime factor in the machine fabrication, it was decided not to convert this equipment.

A detailed investigation of the equipment required for soil mechanics showed that there were two possible equipment that could be used in the development of a tension-compression machine. The first was the unconfined compression equipment which was used to determine the unconfined compressive strength of soil. However, this equipment could only compress up to a load of 500 lbs. Since testing of reinforcing bars requires a higher capacity, this equipment would therefore not be used.

A second compression equipment in the soil mechanics laboratory was then analyzed. It was a compression machine used for determining the California Bearing Ratio. The maximum compressive strength that this equipment could deliver was 5000-10,000 lbs depending on the CBR equipment used. Most equipment were found to be made up of an apparatus consisting of a jack or a set of gears located at the bottom and all sides covered. This type of equipment made its conversion into a tension-compression equipment impossible. It was however discovered that there were California Bearing equipment whose compressive force was delivered by a jack located at the base of the equipment which consisted of a channel. An example of this is shown in Fig. 1.

A design was therefore prepared which could convert the CBR equipment into a tension-compression machine. The basis of the assumption was that with a load of 5,000-10,000 lbs it could test a one fourth inch diameter reinforcing bar for its tensile strength. If the CBR equipment is converted into a tension-compressive equipment, the cost of doing it would be minimal. The reason for the cost being minimum was that only a very small amount was needed for the conversion process.

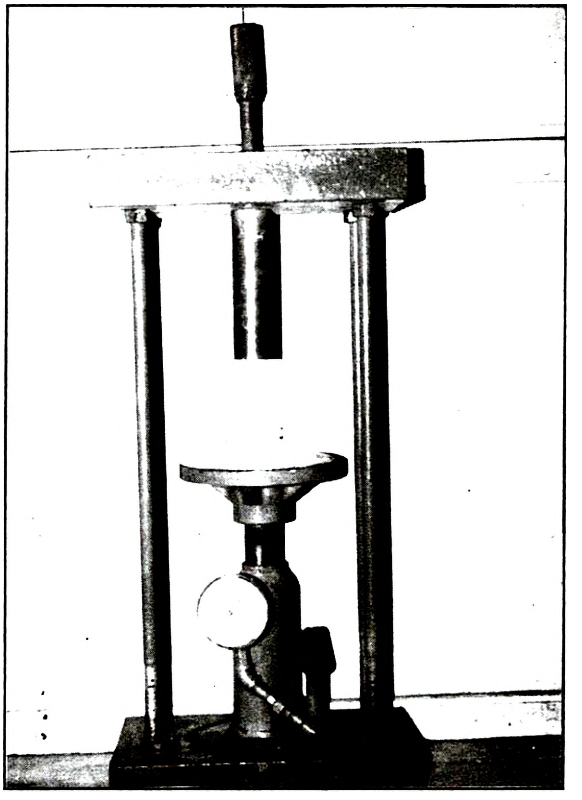

Figure 1. CBR Setup

The process consisted of boring two holes on the top and bottom channels of the equipment. Both holes were equidistant from the center and did not affect the compressive forces. In order to convert the CBR into a tension-compressive machine, there was a need to transfer the base channel of the equipment to the top. In turn, the top channel of the CBR equipment was transferred into the bottom part and acted as the base of the equipment. In doing this, no change was done on the equipment except for the boring of the two holes into the channel.

The equipment however could not yet function as a tension-compression machine. There was a need to provide additional parts to be placed in the equipment. The first part added was a yoke placed on top of the jack. At the bottom of the channel in which the jack was located, another yoke was attached. Both ends of the lower yoke were attached to the ends of the upper yoke within detachable steel bars. All these yokes were attached to the upper channel.

In the lower yoke attached to the upper channel, a hole was bored at its center and a shaft going down was attached and bolted to its bottom. At the bottom channel a shaft was attached to the channel with a bolt. The shaft was located at the center of the channel. This is shown in Fig 2.

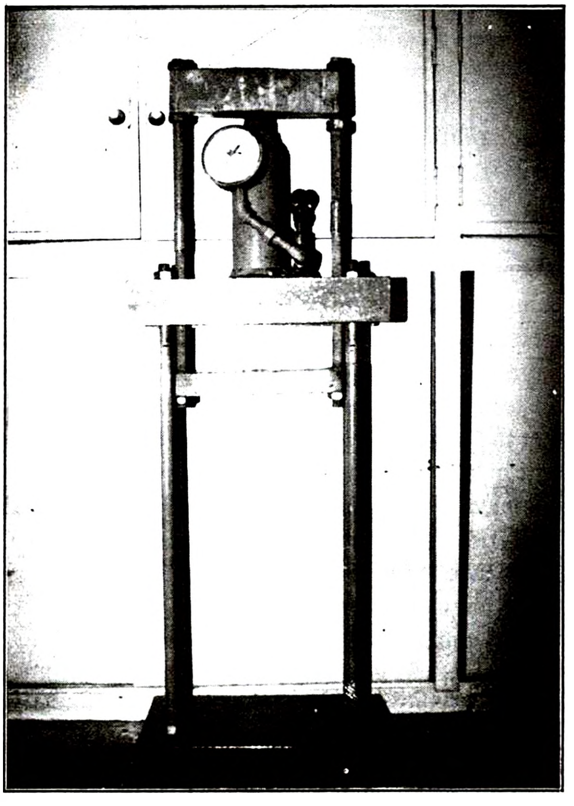

Figure 2. Conversion of CBR Equipment

Both shaft ends have inside threads. The purpose of the threads was to attach bars to be tested for tension to both shafts. When the bars were properly placed a steel bar was attached for the tension and the testing of the steel bar was ready. This is illustrated in Fig. 3.

The jack was then closed and a force exerted. This force was transferred to the top yoke. In turn, the force was conveyed to the lower yoke of the upper shaft in a vertical upward movement. Since the bottom part of the steel bar was attached to the shaft which in turn was attached to the base, it was therefore subjected to a tensile force. In order for failure to take place at the right point, the tensile load was applied at a very slow rate. As the tension bar elongated, a mechanical strain gauge recorded

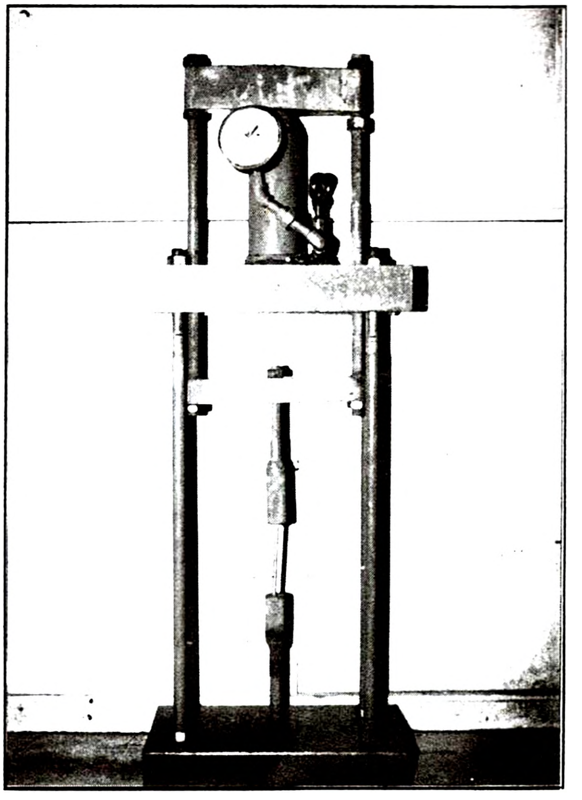

Figure 3. Tension-Compression Machine

the deformation taking place. When it was almost time for the steel bar to break, the mechanical strain gauge was removed in order to prevent its being damaged. What was important was to determine the yield strength of the steel bar.

Two important stresses have been recorded based on the tension test. The first was the unit strain which was based on the results of the reading of the mechanical strain gauge which received the strain. This value divided by the total length of the sample is the given value of the unit strain. The second important data that was recorded was the unit stress which was equal to the force delivered by the jack divided by the area of the reinforcing bar.

The tension-compression machine could also be used for several other tests. Among these are: as a compression machine, it was used to test the flexture strength of wood and concrete. It can also be used to determine the shear stress of wood, compression strength of wood and tensile strength of wood when used as a tension equipment. The five different tests which could be done by this machine made it so versatile inspite of the low cost of fabricating the equipment including all the attachments.

The results of the various tests undertaken by the tension-compression equipment were analyzed and evaluated. It was found that by compression, the results of the various values of failure compared to when tested in a UTM was not very large. With the above assumption, it was recommended that this equipment could be used in any CE material testing laboratory in need of this type of equipment.

The need for a low-cost tension-compression machine was now answered. It could not only be used as a CBR equipment but also for a lot of other tests as previously mentioned in this paper. The results show that the effort in developing this equipment was worthwhile since it made available for use an equipment which would do a tension test at a very low cost.

CONCLUSION

An analysis of the performance of the tension-compression machine that was developed in this research work showed several advantages and are the following:

a. The cost of fabricating the tension-compression equipment was minimal.
b. The cost of converting the equipment from a CBR compression equipment to a tension-compression was minimal.
c. Several other material testing procedures could be done by this equipment which will benefit the students using the laboratory.
d. The process of converting the equipment into a tension-setup from compression takes a very short time.
e. Some of the tests that could be done by the equipment exceeded what is required by the TPEE minimum standards.

Although the advantages of using the equipment are substantial, it should however be mentioned that it also had defects and among the important ones are the following:

a. The rate of applying the load could not be easily controlled since it was done manually.
b. Tension test was possible for minimum diameter bars only and both ends of the bar had to be threaded in order that it can be attached to both shafts.
c. The accuracy of the results was not as high as the results of the mechanical tension-compression.
d. The stress-strain curve cannot be plotted by the machine automatically.

RECOMMENDATIONS FOR FUTURE WORK

The work undertaken to develop a low-cost compression-tension machine has been completed. There is, however, a need to continue the development of a much better tension-compression machine. The Civil Engineering laboratories need a low-cost mechanized tension-compression machine. One of the advantages of a mechanized tension-compression machine is that the rate of loading can be regulated while doing the test. The advantage of a slow rate of loading is that the location of failure point is accurate. This will in turn give the desired results which a hand operated tension-compression equipment cannot easily do. If this problem can be solved in the future, it will help upgrade the material testing equipment of any civil engineering school.

Any future work in this direction will therefore be helpful. Two objectives that should be accomplished are: the need to increase the accuracy of the developed equipment and to design a tension-compression equipment that can deliver a tensile load of 100,000 lbs.

REFERENCES

The TPEAE Report - 1986.

Revised Policies and Standards for Engineering Education- DECS Order No. 102, 1989.

Engineering Education in the Philippines - Dr. Francisco Viray, 1993.

SOLID WASTE MANAGEMENT SYSTEM IN ILOILO CITY

SMILETA GRACE C. CUALES
Chemical Engineering Department, Central Philippine University

Abstract---*An ever increasing problem faced by urban areas in our so-called advanced societies lies in the disposal of the residues from production and consumption processes. Although residents of Iloilo City throw away less than one-fourth of what the Australians discard, the amount generated by more than 335,000 Ilonggos also poses a big disposal problem. The average resident in the city generates about 0.52 kg of household refuse per day. In Iloilo City, about 64,000 tons of municipal solid wastes were generated for the year 1995, and this figure is currently expected to grow at an annual rate of 6%. Municipal or urban solid waste is produced by all sections in the community. It includes wastes produced in public market, commercial and industrial (63% by volume), residential (35%), and hospitals (2%). A characterization study on the waste arising in the city showed the following compositions by weight: food and kitchen wastes (51.2%), paper (20.3%), yardwaste (7.7%), plastic (6%), tin (5%), cardboard (4.7%), glass (2.7%), textile (1.3%), and rubber (1.1%). The main guiding principle adopted to dealing with the solid waste problem in Iloilo City is the hierarchy of waste management, an integrated approach which includes: waste minimization/waste prevention, recycling/re-use, materials recovery including composting, and sanitary landfill.*

INTRODUCTION

All over the world, the problem of urban solid waste is already assuming intractable dimensions. In the Philippines, much industrial growth has taken place particularly in the 1950s and the 1970s (Britannica). Many factories are licensees of foreign companies or act as subcontractors for foreign firms, turning out finished products for export from imported semifinished goods. Major manufactured goods include processed foods and beverages, petroleum products, textiles and wearing apparel, and chemicals.

The advent of high rise buildings, supermarkets, institutions, hospitals, and industries have given rise to problems in urban solid waste. Urban solid waste which includes household refuse, street litter, discards from food preparation, commercial and industrial waste, and hospital waste is a serious problem not only in Metro Manila but also in Iloilo City. Such waste has a variety of properties that make it a threat to the environment and to health if mishandled during collection, transport, and disposal.

Iloilo City, the capital of Iloilo Province is the sixth among the ten highly populated urban centers in the Philippines with a population of 309,505 people for the year 1990. (EMB,1990). It has a land area of 6,852 has. (68.52 sq. km) and is composed of six districts namely: Arevalo, City Proper, Jaro, La Paz, Mandurriao, and Molo. The city has attracted large numbers of rural people who hope to avail of better economic opportunities. However, they often end up living in slums or along the creeks, and find work as low paid unskilled laborers due to limited opportunities.

In 1995, some 64,000 tons of solid waste were disposed of in Iloilo City. Waste production has grown closely in proportion to Gross Domestic Product (GDP) of 6% per annum. Waste quantities are increasing both in total terms and on a per capita basis. It is expected that the annual waste quantities would increase to 92,944 by 2000 and 187,527 tons by 2009, if the rate of increase is allowed to continue unabated.

Landfills are the most common refuse disposal method used around the world; however, there are many drawbacks. Land is a limited and high priced resource in urban areas. As every city expands, this resource becomes more and more scarce in the vicinity of the city, thereby pushing landfills further into the countryside and increasing waste transport costs.

Additionally, leachates from landfill become a problem when the groundwater in surrounding areas is rendered useless due to contamination. Open dumping of municipal solid waste could also create breeding grounds for pathogens leading to outbreaks of disease.

The Iloilo City government has designated a disposal site for domestic and commercial and industrial solid wastes situated in Calajunan, Mandurriao which is about 7 kilometers from Iloilo City proper, and covers an area of 20 hectares. An average of 400 cubic meters of refuse are dumped there per day. The big bulk of these , which is 63% comes from the public market and commercial and industrial establishments, 35% from the residential, and 2% from the hospitals. The method of disposal used is open dumping.

The solid waste management in Iloilo City has a limited expertise in handling and disposing of such waste, resulting in problems at facilities and during transport. The high cost of disposal also discourages some waste producers from using proper methods of disposal, and more often leads to indiscriminate dumping of wastes.

The Calajunan dumpsite has been operational for 7 years now, and with the increasing volume of solid wastes dumped there everyday, the dumpsite will be filled beyond its capacity in less than 20 years, thereby forcing the government to look for a new dumpsite.

General Objective. This study seeks to attain the following general objective: To develop an efficient municipal solid waste management system for Iloilo City.

Specific Objectives. This study aims also to: 1) design a system for waste avoidance and reduction at source; 2) improve the storage, collection, transport, and disposal methods; and 3) develop a recycling system for material and energy recovery.

Significance of the Study. It is expected that this study will: 1) help increase the level of awareness of the public on the proper and efficient methods of storage, collection, transport, and disposal of municipal solid waste 2) help reduce waste entering the landfill, conserve landfill site capacity, and minimize leachates resulting in a clean and healthy environment 3) recover materials and energy and help improve economy.

PRESENT STATUS OF SOLID WASTE IN ILOILO CITY

Total urban solid waste generation rates in Iloilo City are of the order of 0.20 ton/person/yr or 0.52 kg/person /day with a daily total of 174 tons/day for the city for the year 1995. (Buensuceso,1995). Typically, in an Asian country, like the Philippines, waste is highly organic and wet with low levels of plastics, paper, glass, and tin. (Manalo, 1988). The result of a desk study on the solid waste arising in Iloilo City with a projected population of 337,220 people in 1995 is shown in Table 1.

The total waste stream for Iloilo City can be classified into three sources namely, public market, residential, and hospitals. Table 2.

Forecasts of Solid Waste Generation

For the purposes of the study, a representative population for the period 1995-2009 is required. A population of 309,505 for the year 1990 as reported by NSO(1990) is considered as the base data. The average growth rate from 1990-1995 is taken as 1.73%. It is assumed that there is a 5% increase in growth rate for the next five years and so on. A 6% growth rate in GDP (Gross Domestic Product) and 6% growth rate in waste generation rate are considered. Fig. 1 shows a comparison between waste generation at variable and constant rates over time.

In the five years from 1990-1995, the city's solid waste production grew from about 44,000 tons to 64,000 tons per year. This is expected to grow to 92,944 tons by year 2000 and to 187,527 tons by 2009. Table 3.

Storage

Based on the results of Family Income and Expenditure Survey for 1988, about 72% of the total number of households in the province are considered poor. (NSO, 1990).

Most low income families in Iloilo City do not have garbage bins or receptacles and garbage is dumped in the backyard, canals or to nearby open communal dumps, or burned. For middle to high income families, garbage is placed in various containers ranging from plastic and paper bags to native baskets (kaing), cardboard cartons, sacks, and plastic bins.

Most receptacles are unsuitable for proper storage. Because of the open nature of the container, breeding of flies and other vectors is not limited. In residential areas, it is a common practice to keep the receptacles inside the premises to avoid loss, and brought outside only during collection time.

Collection and Handling

Iloilo City has a system of solid waste collection but is not quite efficient just like Metro Manila as only 70% of the waste generated is collected and

Material Type	Composition (% by wt)	Weight (tons/day)	Weight (kg/day)	Volume (cu.m/day)	Composition (% by vol.)
Food and Kitchen Wastes	51.20	89.09	89,090	306.15	23
Paper	20.30	35.32	35,320	396.85	30
Yardwaste	7.70	13.40	13,400	132.67	10
Plastic	6.00	10.44	10,440	160.62	12
Tin	5.00	8.70	8,700	97.75	7
Cardboard	4.70	8.18	8,180	163.60	12
Glass	2.70	4.70	4,700	23.98	2
Textile	1.30	2.26	2,260	34.77	3
Rubber	1.10	1.91	1,910	14.69	1
Total	100.00	174.00	174,000	1331.08	100

Total Population for 1995: 337,220 Total Waste/day: 174 tons

Table 1. Solid Waste Characterisation in Iloilo City

Material Type	Public Market, C & I		Residential		Hospitals		TOTAL
	volume (m³/day)	weight (kg/day)	volume (m³/day)	weight (kg/day)	volume (m³/day)	weight (kg/day)	(kg/day)
Food and Kitchen Wastes	192.87	56,125	107.15	31,181	6.12	1,781	89,087
Paper	251.57	22,390	139.76	12,439	7.99	711	35,539
Yardwaste	83.86	8,470	46.59	4,706	2.66	269	13,444
Plastic	100.63	6,541	55.91	3,634	3.19	207	10,382
Tin	58.70	5,224	32.61	2,902	1.86	166	8,292
Cardboard	100.63	5,032	55.91	2,796	3.19	160	7,987
Glass	16.77	3,287	9.32	1,827	0.53	104	5,218
Textile	25.16	1,635	13.98	909	0.80	52	2,596
Rubber	8.39	1,091	4.66	606	0.27	35	1,732
Total	838.58	109,795	465.89	60,998	26.61	3,484	174,277

Public Market, C & I: 63% Residential: 35% Hospitals: 2%

Table 2. Solid Waste Composition by Volume

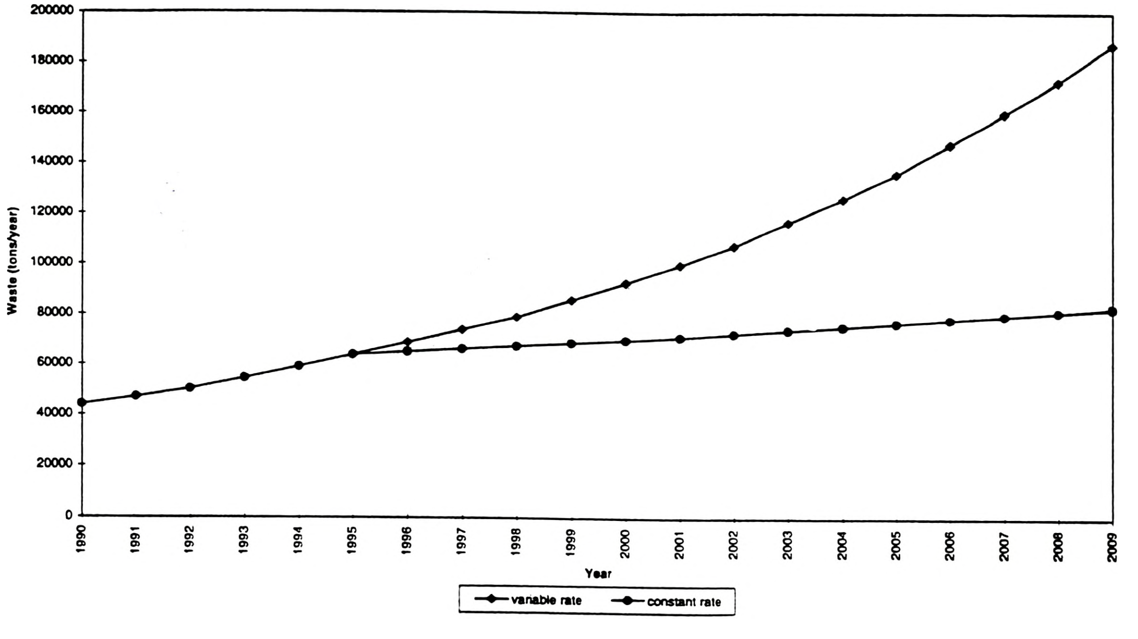

Figure 1. Iloilo City Solid Waste Generation (1990-2009)

Table 3. Solid Waste Generation Forecast in Iloilo City

Year	Popularion	kg/person/day	tons/yr
1990	309,505	0.39	44,058
1991	314,859	0.41	47,119
1992	320,301	0.43	50,272
1993	325,848	0.46	50,272
1994	331,485	0.49	59,286
1995	337,220	0.52	64,044
1996	343,357	0.55	68,929
1997	349,606	0.58	74,012
1998	355,969	0.61	79,257
1999	362,448	0.64	85,991
2000	369,044	0.69	929,44
2001	376,097	0.73	100,211
2002	383,284	0.77	107,722
2003	390,608	0.82	116,909
2004	398,073	0.87	126,408
2005	405,680	0.92	136,227
2006	413,794	0.98	148,014
2007	422,070	1.04	160,218
2008	430,511	1.10	172,850
2009	439,121	1.17	187,527

Notes:

Population Growth Rate:

1.73% from 1990-1995

Assuming a 5% increase in the growth rate for the next succeeding years

Waste Generation Growth rate: 6%

disposed of. (Manalo, 1988). The rest are dumped to vacant lots or to nearby creeks, burned, or composted. The primary collection and handling process involves collection from streets to wooden pushcarts or improvised wheeled carts. The rubbish is then dumped back on the ground, to be picked up by rakes and baskets and put into trucks. This results in wastage of labor and waiting time for vehicles, apart from the great health risks to which the workers are exposed because of regular skin contact with wastes during collection and loading. These wastes attract rats, dogs, and cats which are possible carriers of diseases.

Furthermore, there is also a lack of community containers or an enclosed storage place of proper design for collected street and house wastes. In most districts, community containers are not provided. Because of this, garbage is dumped everywhere possible. These dumps are invaded by scavengers and animals which scatter the waste. The rats have access to food and fly larvae can migrate and pupate in the vicinity.

Collection Systems

In Iloilo City, the collection systems basic to Asian countries are also employed. The three collection systems are communal collection, block collection, and kerbside collection.

Collection from Communal Site. In this system, the collectors just collect the waste from the communal storage or the designated dumping area which may require delivery of the wastes by the householder over a considerable distance. At the downtown area, wastes are put in plastic bags or cartons and placed at designated places usually at every corner of the street.

Block Collection. In this system, a collection vehicle travels in a regular schedule and routes, and the householders deliver the wastes to the vehicle at the time of collection.

Kerbside Collection. In this system, the residents place their bins on the footway in advance of the collection time and remove them after they are emptied. Kerbside collection is not successful in Iloilo City because: 1) the bins are sorted through by scavengers 2) the bins are stolen because the householder fails to retrieve the bins quickly 3) traffic accidents are caused by bins rolling on the road 4) the bins are sometimes turned over by animals which scatter the waste

Industrial waste, hospital waste, and building and demolition waste are not collected by the city government. A vast amount of industry exists in the province and in the city and the collection and disposal of waste is dealt with either by the industries themselves or by contractors hired to remove the waste.

The operation of collecting and hauling of garbage as well as street cleansing in the city is managed by the Office of Public Services (OPS), with an employment of 340 personnel.The OPS has established a schedule and routing of solid waste collection. The city is divided into nine(9) routes. Every route has a schedule of collection: daily (including holidays), twice daily, twice a week, and three times a week. (Buensuceso,1995). There is some two-shift working in order to accommodate late-night collections from the public markets, commercial as well as residential areas. The night shift is handled by the private collector and the day shift is handled both by the private collector and the city working for eight (8) hours per day.

Transportation

The six (6) districts of the city are served by 13 collection vehicles with a capacity of nine (9) cubic meters each. Eight (8) of these are owned by a private contractor and five (5) are owned by the city government.

Compactor container vans are useful for the collection of soft domestic waste (i.e. food wastes, paper, plastics, etc.). These collection vehicles are equipped with internal compaction mechanisms, with enclosed top and side or rear-loading, and can carry more waste in terms of weight, thus reducing the number of conveyance tours to the disposal site. Obnoxious odors, dust and litters blown by the wind are avoided because the collection vans are closed. Unfortunately, three (3) compactor type vans are not enough to serve six (6) districts with 309,505 population.

Open dump trucks are observed to be kept uncovered and, during journeys and frequent starting and stopping, the materials tend to spill on the roads. On the other hand, these are ideal for domestic hard waste such as garden waste, tree prunings, and other bulky wastes.

Disposal

Disposal of waste in Iloilo City is through open dumping. Located in Calajunan, Mandurriao, Iloilo City, seven (7) kilometers from the city proper, the dumpsite which covers an area of 20 hectares is now seven (7) years in operation.

Only 40% of the total cost of waste management is spent on collection, transportation, and disposal services by the city. The total cost of collection and disposal is P 150/ton (US$ 6/ton) daily. The remaining 60% is spent on Administration and Overhead Expenses and Equipment Purchases.

Landfill Site Management

Financed by World Bank, the proposed method of disposal for the Calajunan site is sanitary landfill, using an earth covering of 100 millimeters thick. Of late, it is observed that during the rainy months, waste is just dumped near the entrance of the site. The dumptrucks could not drive through because the way is slippery and muddy. There are no earth excavations that can be seen and sanitary landfilling is no longer practised.

The standard of operation of a landfill determines to a large extent its impact on the environment. Regrettably, Iloilo City has a poor standard of site management for Calajunan dumpsite and this leads to environmental and public health problems such as: 1) water pollution from leachates; 2) rats, flies, and mosquitoes infestations; 3) spontaneous fires and associated toxic emissions; 4) serious odor problems; 5) litter problems; and 6) the number of scavengers living and working in the dumpsite is increasing.

About 40% of the Calajunan dumpsite area is already full. It is calculated that with the current waste generation trends, the existing disposal site facility would be exhausted by the year 2005. To date, no abandonment plan has been made as to what should be done with the site after it is fully closed.

EVALUATION OF PREFERRED SYSTEM FOR ILOILO CITY

The strategic plan for managing Iloilo City's solid waste is based on a mix of options which can be considered practical and appropriate for the city. These options are firstly to reduce to a minimum the quantity of waste requiring disposal by: 1) encouragement of waste minimization/waste prevention; 2) optimizing separation at source for recycling/re-use; 3) development of materials recovery including composting. The option then available for disposing of the remaining waste quantities is by sanitary landfill.

The waste reduction/waste prevention and disposal options and their potential to improve the existing system in Iloilo City are discussed in the following: 1) waste minimization, and 2) source reduction.

Solid waste reduction can be achieved in two ways: 1) Primary Reduction: reducing the amount of waste created with consumer demands playing a key role; and 2) Secondary Reduction: turning potential waste into something of positive value through re-use, composting, or placing material out for collection by others.

Primary Reduction - Consumer Choice!

Reducing Waste Through Consumers' Choice (Hirschhorn and Oldenburg, 1991)

Unpackaged Products (e.g. fruit and vegetable)

1. Buy less (buy more frequently)
2. Buy things that last
3. Buy small
4. Favor over packaged products
   Packaged Products (e.g. cereals, detergents)
5. Buy large economy sizes
6. Buy concentrated products
7. Buy products with the fewest layers of packaging Products for packaging purposes (e.g. carry bags, wrapping paper)
8. Say no - take your own bag

9. Buy packaging that can be re-used
10. Consolidate

Secondary Waste Reduction - Waste is a Resource!

Even if consumers buy more environmentally friendly products, generation of waste is still unavoidable. It is therefore important for consumers to: 1) reduce organic waste leaving the household 2) separate waste for re-use by others (e.g. donate used clothing to charity) 3) re-use products (e.g. buy a re-usable electric razor than a disposable one) 4) repair products rather than throw away broken ones.

Waste minimization, or avoiding the generation of waste by changes to manufacturing procedures or in other ways, has been applied with some success to industries producing liquid waste and intractable waste. Waste minimization is taken to include waste avoidance/elimination, waste areduction (quantity or toxicity), re-use and recycling.(Moore, 1995).

In the Guangzhon Chemical Works in the People's Republic of China, there is a Chlor-Alkali plant which was built over twenty years ago. Unlike most such plant in the world, it does not pollute. All the waste chlorine streams are collected and used to make bleaching powder which is then sold. The sludge from the electrolysis cells is sold as filler to a local rubber factory, and there is no mercury pollution because since its inception the plant has used diaphragm cells.(Royston,1990).

In Malaysia, old tin mine sites have been converted into recreational areas, and in the Philippines, site of the Second World Recycle Conference, examples of success stories of turning waste to profit abound, particularly in the conversion of forest wastes and special fast growing trees into energy. (Royston,1990).

Waste Minimization Program

There are a number of waste minimization projects that are implemented in the Philippines to provide assistance to industrial and agri-business firms in solving their environmental pollution problems related with industrial and agricultural operations.

The Industrial Environmental Management Project (IEMP) is a project launched by the Department of Environment and Natural Resources (DENR) and funded by the United States Agency for International Development (USAID). It aims to create a broadly-based partnership between sectors which include: government, business, and non-government organizations (NGOs). (EMB,1992). The objectives of this project are to: 1) encourage sustained growth in the industry 2) reduce pollution from industrial activities 3) improve human health and the environment

Another economical scheme which is being promoted by the national government is the Integrated Food Processing System (IFPS). (Manalo,1988). It is designed to maximize utilization of the raw materials. The main features of the system are 100% utilization of raw materials and diversification into multi-product line hence reducing problems of food wastage and waste disposal.

An example of this is when applied to fully ripe fruits, whose major products are jams, jellies, bottled preserves in syrup, dehydrated glazed fruits or juice. The by-products from the seeds, peelings, and trimmings can be utilized as wine, or vinegar, animal feeds or fertilizer.

Recycling/Re-use

Re-use and recycling of materials represent a way of indirectly recovering the energy content of municipal solid waste and slowing down the rate of depletion of natural resources. In the Philippines, old newspapers, magazines, or other kinds of paper are sold by the kilogram and recycled as additional pulp for the paper industry. Catsup and mayonnaise bottles are sold to oil, vinegar, or soy sauce local entrepreneurs who cannot afford to buy new ones. Old fluorescent lamps are recycled and sold at lower prices. This is a new livelihood source at Smokey Mountain launched by the Department of Labor and Employment (DOLE) in coordination with the Institute for the Protection of Children. (Manalo,1988).

Tires aside from being converted into slippers, flowerpots and doormats are now being made into artificial reefs, a safe haven for marine life. Most coral reefs in the Philippines have been damaged due to illegal dynamite fishing method called "Muro-Ami".

In Sydney, the Metropolitan Waste Disposal Authority (MWDA), encourages recycling by directing the public to recycling centers at its regional landfills and transfer stations and to other facilities and services offered by private and public organizations. Recycling is best undertaken at the source by encouraging householders and other generators to separate wastes for collection or to deliver the component products to receival points.

(van den Broek, 1987).

Recycling is actively practiced at most stages in the solid waste management system in Iloilo City,just like in many cities in developing countries. Source separation has to a certain extent occured effectively in the city by the scavengers going from door to door and buying reusable items.

Composting

Composting is very compatible with recycling. While composting is the biological decomposition of the organic components in the waste stream, it is recycling that will help improve the product by removing undesirable material such as glass, metal, and plastics. Composting is by far the most responsible technical solution for many developing cities, especially where the climate is arid and the soil is in serious need of organic supplements. (Holmes,1984).

Cellulolytic fungi can hasten the process of composting by immediate increase in temperature of piles and by rapidly increasing populations of active decomposers.

In the Philippines, a compost activator called genus Trichoderma is used in the National Program on Rapid Composting. This fungus is currently mass produced in all regions of the country by the provincial or regional centers of Department of Science and Technology (DOST), Department of Agriculture (DA) and State Colleges and Universities, and sold at P7.50-P12.00 (US$0.30-US$0.50) per kg activator. (Cuevas,1992).

Landfills

According to Williams (1991), landfills are the one form of waste management that nobody wants but everybody needs. There are simply no combinations of waste management techniques that don't require landfilling to make them work. Of the four basic management options (composting, incineration, sanitary landfill, refuse-derived fuel),landfills are the only management technique that is both necessary and sufficient. Although landfill is the final step in all waste treament, it is by far the cheapest and most widespread method of waste disposal. (Barbiroli,1994).

CONCLUSIONS AND RECOMMENDATIONS

Solid waste management encompasses many interrelated elements that must be well orchestrated to be effective. Appropriate solutions exist that can be afforded by the city government. However, there is no universal solution to the problem of refuse disposal; there is no single best method. Any of the existing methods or a combination of them can be used but the methods adopted must be related to local social and cultural conditions. For an efficient municipal solid waste management system in Iloilo City, the following hierarchy of waste management, Fig. 2, and an integrated approach to waste management, Fig. 3, are recommended.

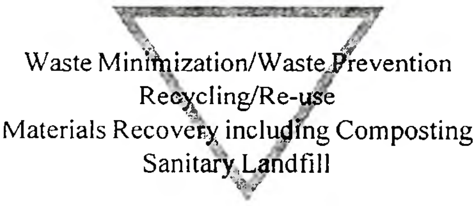

Figure 2. Hierarchy of Waste Management

To further improve the existing system, the following elements must be considered:

Storage. In order to have sanitary and effective storage of refuse in house premises, the following steps must be taken:

* All household units must have standard garbage bins. The garbage bins must have tight-fitting lids, must be water tight, durable, and resistant to corrosion.
* Surveys must be carried out to establish the house population density and also to gauge public interest in and support for the system about their attitudes toward waste disposal and recycling issues.
* The capacities of the garbage bins must be related to house population density and the frequencies with which the garbage bins are likely to be emptied.
* The city in care of the Office of Public Services (OPS) must provide the garbage bins and sell to those who may wish to buy them.
* There must be regular health education of the people on the proper use of the garbage bins.
* The Mayor's office shall pass a decree setting out, in detail, the conditions of household refuse collection with regard to the receptacles to be used, pick-up frequency, and the various steps required for recovering and treating the solid wastes.

Separate Collection. In order to facilitate the recovery of certain wastes, the city by means of a city ordinance may require that certain wastes be sorted (paper and board, glass, plastic) and brought

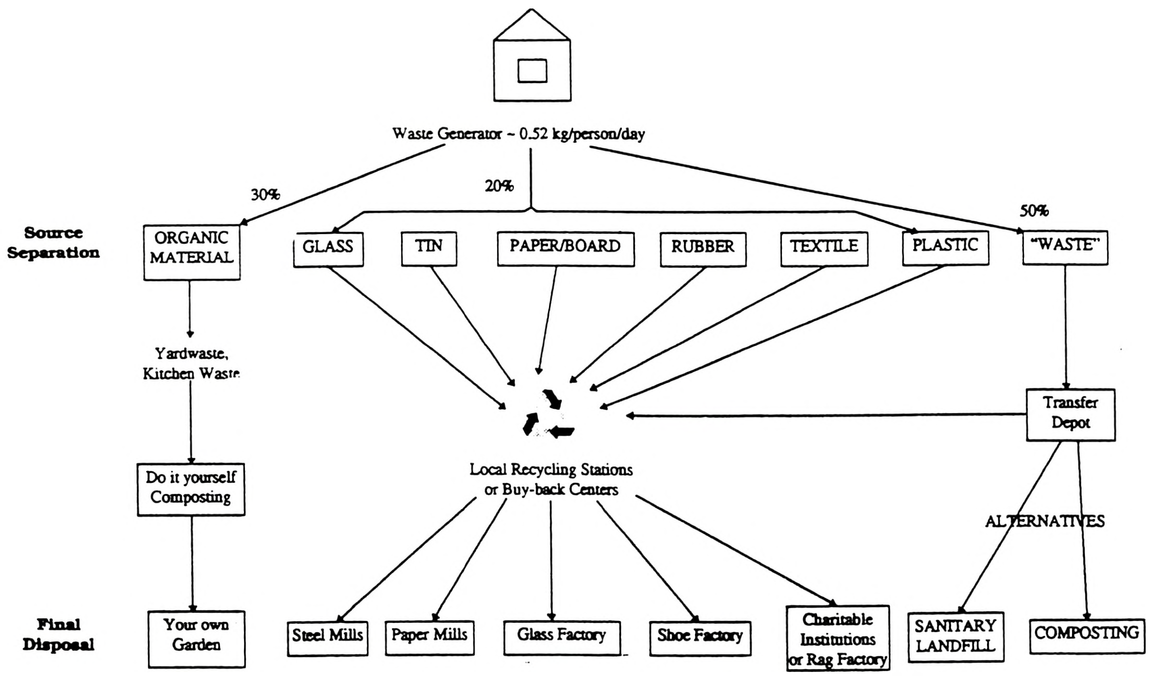

Figure 3. Integrated Solid Waste Management Scheme for Iloilo City

to local recycling stations or buy-back centers, provided by the city. Organic waste must be separated from inorganic at the household level so that the compostable materials may be collected and brought directly to the composting plant.

Organized/Controlled Scavenging. The idea is to hire as many of those currently engaged in scavenging. They will make the rounds of households and be authorized to buy at pre-determined prices those recyclables which have been previously sorted by the household. The materials will be redeemed at redemption centers or buy-back centers owned by the city at about 20% to 25% more than what they paid for them, and where the materials can later be sold to junk dealers.

Primary Collection. Picking up of wastes once only could be applied using simple indigeneous equipment such as pushcarts or pedal tricycles working in conjunction with dumptrucks and compactor-type vehicles.

The expansion of primary collection through the introduction of low cost locally-made pedal tricycles ("tri-sikad") and an optimal number of simple short-range dumping stations or transfer depots, would substantially reduce the cost of collection and transportation. Depending on the density of the population, one transfer-point may cover 4,000-6,000 population. This will help reduce the requirement of vehicles and fuel.

Collection from Central Points Only. The idea is that the people bring their wastes themselves (or via a person responsible for handling the waste) to a central strategically located collection point. These points should be within some walking distance from the houses. The collection point may be: An open space surrounded with concrete walls, or trailers. Wastes must be placed inside plastic bags and sealed to prevent emission of odors and leachates.

Street Cleansing. The success of street cleansing depends on two main elements: 1)sufficient garbage/ litter bins are frequently emptied; and 2) cooperation of the population.

Promotion campaigns can improve people's motivation but they will only have a lasting effect if the garbage bins are really emptied everyday.

Public Education, Participation, and Awareness. The system needs the active co-operation and participation of citizens. This can be achieved only when the citizens become aware of the ill-effects of the existing systems and the advantages of using proper methods. Environmental education of the population should cover all segments of the population, from school-going children to senior citizens.

The education program must reach into the school, the university, the office, the restaurant, the public market, and must seek to have an effect on the daily lives of the citizens through the process of motivation.

Sanitary Landfill. The area method of landfilling is a solution for superficial or shallow ground-water table. It is recommended that a final cover material (earth or compost from municipal solid waste) one (1) meter thick will be spread over each layer of waste, two (2) meters thick.

Several precautions will be undertaken at the landfill site against pollution of the environment, which include: the areas filled up with refuse must be regularly covered with fresh earth, and other precautions, like spraying of insecticides for fly, and rodents control; and fences will be erected to prevent garbage and paper from blowing away from the site. Any refuse scattered inside the site ground or spilled during vehicle entry and exit will be collected.

Leachate Control. So that water does not percolate laterally into the side of a cell, a liner is used, or the fill area is situated so that the gravity does not take percolating run off towards the cells. This is recommended for the area or trench method. As stated by Tchobanoglous (1993), compost from yardwaste and municipal solid waste, the geosynthetic clay liner, and clay are effective in limiting the entry of surface water into the landfill.

For treatment of leachate, biological processes such as aerated lagoons or activated sludge plants are recommended. The treated leachate may then be disposed of to the nearby creek.

Landfill Gas Control. It is suggested that landfill gas monitoring and extraction systems need to be installed at the site after closure to minimize malodors and to prevent any damage to future vegetative rehabilitation at the site and ensure that the site is compatible with its planned recreational end uses.

ACKNOWLEDGMENT

This paper is an output of a six-month research study in the University of New South Wales, Sydney, Australia, supported by DOST-ESEP. The author wishes to thank her adviser, Prof. Stephen J. Moore, for his helpful guidance and Engr. Benjamin O. Cuales, Jr., for sending the needed data.

REFERENCES

Barbiroli, G., 1994, 'Technological Innovattion and Costs of Municipal Solid Waste Treatment' in Curzio, A. Q., et. al.(eds.), The Management of Municipal Solid Waste in Europe.

Buensuceso,P.D., 1995, City Government Department Head II, Office of Public Services, Iloilo City.

Cuevas, V.C., 1992, 'Composting Solid WAstes in Urban Areas', Paper delivered at the Seminar Workshop for Local Government Solid Waste Managers organized by the Environment Management Bureau of DENR held on Oct. 19-23, 1992 in Tagaytay City.

EMB, 1990, 'The Philippine Environment in the Eighties'. Environmental Management Bureau.

EMB, 1992, 'Business for a Cleaner Environment', Environmental Management Bureau and Department of Environment and Natural Resources.

EPWV, 1991, 'Ecological Profile of Western Visayas'.

Hirschhorn, J.S., K.U, Oldenburg,1991, 'Prosperity Without Pollution- The Prevention Strategy for Industry and Consumers', Van Nostrand Reinhold, New York, 1991.

Holmes, J. R., 1984, 'Solid Waste Management Decisions in Developing Countries' in Holmes, J.R., (ed.), Managing Solid Waste in Developing Countries, John Wiley & Sons, New York, 1984.

Manalo, J. A., 1988, 'Recycling and Recovery of Materials from Wastes -Philippine Experience', in Andersen, L. and Moller, J., (eds.), International Solid Waste Association (ISWA 88), vol. 1.

Moore, S.J. and S-Y, Tu, 1995, 'Application of the Australian Waste Database to Regional Environmental Management'.

NSO, 1990, 'Census of Population and Housing of Iloilo', National Statistics Office, Region VI.

Tchobanoglous, G., H. Theisen, S. Vigil, 1993, 'Integrated Solid Waste Management', McGraw Hill International Editions, USA, 1993.

The New Encyclopedia Britannica, 15th ed., vol. 25, pp. 550-551.

Van den Broek, 1987, 'Garbage Generation, Composition, Collection, and Disposal in the Sydney Region, in Garbage in the Lower Hunter-Proceedings of the Seminar, May 1987.

Williams, M. E., 1990, 'Integrated Solid Waste Management', in Kreith, F., (ed.) Integrated Solid Waste Management Options for Legislative Action, Genium Publishing Corp., New York, 1990.

WATER QUALITY TESTING AND TREATMENT IN THE PROPOSED CPU WATER LABORATORY

DAHLIA H. PESCOS
Chemical Engineering Department, Central Philippine University

Abstract---*The impairment and progressive deterioration of water systems exposed to pollution in Region VI were not given importance because of the lack of water quality testing and treatment laboratory to monitor and correct them. It is because of this problem that CPU has come up with the plan of putting up a water quality testing and treatment laboratory to monitor and correct them. This paper contains the literature needed in the conduct of a water quality testing and treatment in the proposed water laboratory of Central Philippine University. This includes the measurable characteristics, compounds or constituents found in water which affect its quality; the physical, chemical and biological characteristics of wastewater and their sources; the proper sampling techniques for collection, preservation and transport of water samples; the different methods of water analysis; the treatments appropriate to the removal of various forms of water impurities; the basic principles on how to develop a monitoring program to monitor the quality of water and the requirements of a good laboratory operation and management.*

INTRODUCTION

Freshwater is increasingly becoming a scarce commodity in Western Visayas. Still a large number of people has limited or has no access to safe and clean water because of the fact that, the potential of the region's water resources have not been fully harnessed. The technology needed to handle this does not still exist. And given the current rate at which these resources are degraded, the realization of such potential may never come to pass. There is therefore a need to change the traditional notion of water as an abundant and free commodity to one which must be conserved and utilized wisely.

Region VI is so far considered the number one polluter in the whole Philippines based on the waste dumping category (Marquez, 1995). It is a terrible thing to find out that out of 957.74 ML of the region's generated wastes per year, 702.82 ML per year or 73.6% of it is just being dumped to the water courses without prior treatment. This environmental crime has been known to exist already in the 1980's. Large amounts of organic wastewaters primarily containing molasses,cane juice and malts from sugar mills and alcohol distilleries caused the deterioration of the rivers in the region (Environmental Management Bureau, 1990).

The general objective of this study is for the researcher to have enough background for the conduct of water quality testing and treatment. The specific objectives are to know and use the proper sampling techniques for collection, preservation, and transport of samples from the source to the laboratory in order to obtain reliable results, determine the extent of pollutant removal needed for safe disposal of the treated waste-water based on different water usage or classification, operate and maintain the equipment in the water testing laboratory and to apply the appropriate method for the treatment and removal of specific water pollutants.

This proposed laboratory is expected to perform more comprehensive water quality testing for all parameters suspected to exist at the present in surrounding waters of Region VI. It will be tasked to monitor the quality of public drinking water supply, the discharges of industrial effluents into municipal sewers, and the discharges of secondary treated effluents into small inland rivers surrounding the region. This can also be used to examine whether or not the municipal treatment plants and the industries are meeting the required quality for drinking water and for wastewater disposals.This proposed water laboratory will not only augment the existing services of the Department of Energy and Natural Resources but will be used for educational training of engineering students.

WATER QUALITY CHARACTERISTICS

The measurable physical characteristics are true color (the color which remains after any suspended particles have been removed); turbidity (the cloudiness caused by fine suspended matter in the water); hardness (the reduced ability to get a lather using soap); total dissolved solids (TDS); pH; temperature; taste and odor; and dissolved oxygen.

In general, the physical characteristics of water do not threaten public health, but they affect the aesthetic quality of the water and this determine whether or not people are prepared to drink it.

A number of chemicals, both organic and inorganic and including pesticides, are of concern in drinking water from the health perspective because some are toxic to humans and some either cause or are suspected of causing cancer. Some can also affect the aesthetic quality of water.

Inorganic chemicals in drinking water usually occur as dissolved salts such as carbonates, chlorides, etc., attached to suspended material such as clay particles, or as complexes with naturally-occurring organic compounds. Their presence may result from natural leaching into source waters from mineral deposits; human activities; or corrosion of pipes and fittings. Some are deliberately added to drinking water for disinfection, clarification or public health (e.g. fluoride). By-products of disinfection are the most commonly found organic contaminants.

The most common and widespread health risk associated with drinking water is contamination, either directly or indirectly, by human or animal faeces, and with the micro-organisms contained in the faeces. Drinking contaminated water or using it in food preparation may cause diseases like mild gastro-enteritis, diarrhea, dysentery, hepatitis, cholera or typhoid fever.

Water Quality Criteria

Water quality may be defined as the assessment of the physical and chemical properties of material dissolved or suspended in water.

Water quality criteria may be defined as the scientific information on which decisions or judgements are based about the suitability of water quality for a designated use (Hart, 1980). They are used in identifying if the quality of water are suitable for the values and uses for which they are identified as requiring protection. They are the quantitative (or qualitative) data that predict the chance or magnitude of the effects of a contaminant on a defined receptor under specific environment. These criteria are described in terms of water quality indicators.

There are two main uses of water quality criteria according to Hart (1980): in the development of standards and in assisting the development of water quality management strategies. Criteria are the main inputs of scientific information in the setting of standards. Without this information, standards would be arbitrary and carry little guarantee of adequate environmental protection.

Water quality guidelines translate the criteria into a form that can be used for management purposes. Standards are what guidelines become when compliance is enforced by law.

Water Quality Indicators

Indicators are variables that indicate the presence or condition of phenomena. They reflect the state of any aspect or component of the environment. They act as signs or as early warnings of a problem because they highlight the status quo and what could occur in the future.

The method of selecting the indicator varies with the characteristics of the component, but they all share one requirement. The indicator must respond to changes in the component it is scaling in such a manner that it accurately reflects the magnitude of these changes. Appropriate water indicators have been developed to facilitate in giving direct outcomes.

Water Sampling

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled. This objective implies that the relative proportions or concentrations of all pertinent components will be the same in the samples as in the material being sampled, and that the sample will be handled in such a way that no significant changes in composition occur before the tests are made.

It is essential to ensure sample integrity from collection to data reporting. This includes the ability to trace possession and handling of the sample from the time of collection through analysis and final disposition.

The type of sample container used is of utmost importance. For samples containing organics, avoid plastic containers except those made of fluorinated polymers such as polytetrafluoro ethylene (TFE). For samples containing volatile organics, use glass containers because some compounds in it may dissolve into the walls of plastic containers or may even leach substances from the plastic.

Methods of preservation are relatively limited and are intended generally to retard biological action, to retard hydrolysis of chemical compounds and complexes, and reduce volatility of the constituents. They are generally limited to pH control, chemical addition, refrigeration and freezing. The preservation procedure for the different parameters are given in Table 1.

Water Monitoring

The broad objectives of water monitoring include the conservation of water quality and quantity to assure an adequate supply of water suitable in quality for both public and industrial uses and for the maintenance of fish and wildlife.

Water monitoring is the continuous sampling, measurement, and analysis of the quantity and quality of various liquid streams. These streams may include wastewater streams or plant effluents; water courses such as rivers, lakes, and estuaries; ground water; recirculated streams such as cooling water; power plant streams such as boiler feedwater condensate; or process effluents (Hamilton, 1978).

Monitoring is no longer a solely voluntary procedure. In other countries, monitoring is a legal requirement of a regulatory agency for the prevention, reduction, and elimination of pollution. These include establishing, equipping, and maintaining a water quality monitoring system for all waters. Owners and operators of any point sources are now required to establish and maintain records, to make reports, and to install, use, and maintain monitoring equipment and methods in such a manner as the regulatory agency should provide. Point-source discharge into waters is prohibited unless the discharge is authorized by permit. A substantial monitoring program may be necessary to provide information required by the permit. Such a monitoring system would also be able to provide data to answer inaccurate accusations of harmful or illegal wastewater discharges. Adequate monitoring records can document that a facility was operating in conformance with permit requirements during any particular period of time.

A monitoring program has two main components: System performance monitoring is a wide-ranging assessment of the quality of water in the distribution system and as supplied to the consumer. The data are used for assessing compliance with the guidelines or agreed standards of service and, if necessary, as a trigger for corrective action to improve water quality. Operational monitoring is used to check that the processes and equipment that have been put in place to protect and enhance water quality are working properly. The data are used, if necessary, as a trigger for immediate short-term corrective action to improve water quality, but they are not used for assessing compliance with the guidelines or agreed standards of service.

Water Quality Tests

Water is analyzed to determine its suitability for drinking, cooking, washing and other lesser domestic purposes while wastewater is analyzed to determine its suitability for discharge or the degree of treatment required to render it acceptable for discharge.

The type of test to be performed depends upon the degree of accuracy required, the use of the data and the use of the water. The types of test used on water and wastewater can be broadly classified as:

* Tests for gross pollution such as BOD, COD, suspended solids, ammonia, and grease. These are used extensively for wastewaters.
* Tests for appearance and aesthetic acceptability of waters, such as taste, odor, turbidity and color. These tests are used widely for water supplies.
* Microbiological tests, which are used mainly for detecting indicator organisms in water supplies and effluents.
* Tests for toxins.
* Tests for materials that are a health risk.
* Tests which determine suitability for incidental uses. These are tests which assess corrosivity on the basis of dissolved gases, pH and dissolved salts.
* Operational tests used to check plant performance.

The following are the usual water quality tests performed in the water laboratory, namely gravimetric, titrimetric, colorimetric, potentiometric, general solids, spectroscopic, chromatographic and the like. The method of analysis for all designated parameters are also available in Table 1.

WATER/WASTEWATER TREATMENT METHODS

The most important objective of water treatment is to produce a water that is biologically and chemically safe for human consumption while that of wastewater treatment is to produce an effluent that can be discharged without causing serious environmental impacts.

The commonly used water treatment methods are either physical operations or chemical processes. Biological processes are not suitable in situations where contaminant concentrations are low.

Processes and operations used in wastewater treatment are similar to those used in water treatment except for biological methods.

The principal use of biological treatment is for the removal of easily biodegradable organic compounds, although biological processes are also used for removal of nitrogen and phosphorus in some situations.

In selecting treatment processes for particular applications, the general physical form and the chemical and biological nature of the impurities to be removed are of great importance. Treatments appropriate to the removal of the various forms of impurity are similarly classified under broad headings of physical,chemical and biological processes.

Laboratory Management

With the adoption of more stringent standards for water quality, the importance of laboratory operation and the generation of credible data increases. Competent management is essential to bring about reliable laboratory performance to ensure precise and accurate analysis of samples. Good laboratory management requires that guidelines are made available and procedures are implemented for : inventory of chemicals and equipment; maintenance of equipment and instruments; purchasing; quality; safety; staff and, waste management, and documentation of all methodologies used for analysis of samples.

CONCLUSIONS AND RECOMMENDATIONS

A sampling program to be effective should consist the following steps: (1) a review of existing data (effluent, water quality, hydrologic land use, geology, soils, vegetation); (2) selection of sampling locations (the number of stations is dependent upon the available resources); (3) defining a sampling procedure; (4) selecting significant parameter to be measured; (5) establish a sample analysis procedure; (6) based on available sample results, prepare control charts to help determine minimum sampling interval during highly varying flow conditions; (7) assess the performance (apply statistics); and (8) reporting.

Sample collection and field measurements must be done by appropriate trained staff equipped with the needed sampling equipments and instruments for the specific analysis to be made. The results of any analysis are of value only if the sample is known to represent accurately the water or wastewater being sampled. Data verification should be performed at several levels: (1) field sampling requirements; (2) field measurement; (3) sample preservation and transport; (4) laboratory storage and analysis; (5) regular check of data such as date, site, time, range etc. on entry to the computer, and (6) manual checking of results after entry to the computer.

The number of samples to be taken and the time and exact place of sampling depends on the importance of the analysis, the accuracy required, and the resources available but skilled judgement will be valuable and there may even be a case for simple cost-benefit analysis. Thus, the whole sampling technique will depend upon what is being sampled, why it is being analyzed, and what constituents are to be determined. The type of water quality test to be performed depends upon the degree of accuracy required, the use of data and the use of water.

The choice of treatment processes for any particular application depends on the quality of the raw water, the required quality of the treated water and the economic resources available to pay for both the capital and operating costs of such treatment.

The type and extent of treatment required depends on the nature and degree of the quality deficiences to be corrected. If the water conforms to the desired standards for both chemical content and appearance but subject to occasional minor bacterial contamination, it requires only disinfection. If the raw water is frequently either turbid or coloured, it requires more extensive treatment. Water which contain excessive amounts of either dissolved salts or toxic materials require expensive treatment.

Availability of guidelines and implementation of procedures for inventory of chemicals and equipment, maintenance of equipment and instruments, purchasing, quality, safety, waste management and documentation of all methodologies used for analysis and samples are needed in a good laboratory management.

Further research is recommended for the following: a) Information on what happens to waste in receiving water and their effects on the water, particularly wastes that cause tangible changes in the water itself or significantly affect successive uses; and b) A methodology for keeping track of quality changes and quickly computing the concentration of pollutants at all relevant points of use, as a function of a variety of conditioning factors. The latter includes waste loads at particular outfalls, biological, chemical, and physical conditions and volume of stream flow.

PARAMETER	CONTAINER	MINIMUM SAMPLE SIZE (in ml.)	PRESERVATION	MAXIMUM STORAGE RECOMMENDED	METHOD OF ANALYSIS
Acidity	P, G (B)	100	Refrigerate	24 h	Titration Method
Alkalinity	P, G	200	Refrigerate	24 h	Titration Method
Biological Oxygen Demand (BOD)	P, G	1,000	Refrigerate	6 h	DO Measurement
Carbon, Organic Total	G	100	Analyze immediately; or refrigerate and add HCl to pH<2	7d	Combustion Infrared Method
COD	P, G	100	Analyze as soon as possible, or add H_2SO4 to pH < 2; refrigerate	7d	Dichromate Reflux
Chlorine, Residual	P, G	500	Analyze immediately	0.5 h	Amperometric Titration
Chloride*	P, G	100	None required	6 months	Spectrophotometric
Color	P, G	500	Refrigerate	48 h	Spectrophotometric
Conductivity	P, G	500	Refrigerate	28 d	Electrometric
Cyanide, Total	P, G	500	Add NaOH to pH > 12, refrigerate in dark	24 h if sulfide is present	PreliminaryDistillation/titrimetric/colorimetric
Total Coliforms* Faecal Coliforms	Sterile glass	250	If chlorine is present add 0.1 ml of 10% (w/v) sodium thiosulphate per 100ml of sample. Cool to between 1-4°C	6 h	Membrane Filtration
Hardness	P, G	100	Add HNO_3 to pH<2,	6 months	EDTA Titrimetric Computation
Metals (General)	P(A), G(A)	2,000	For dissolved metals filter immediately, add HNO_3 to pH<2 refrigerate	6 months	
Chromium IV	P(A), G(A)	300	Add HNO_3 to pH<2	24 h	Colorimetric
Mercury	P(A), G(A)	500	4°C, refrigerate	28 d	Flame AAS
MBAS (Methylene Blue Active Substance	G	250	Add chloroform to 0.2% (V/V) of sample and store at 4°C	48 h	Colorimetric
Nitrogen: Ammonia	P, G	500	Analyze as soon as possible or add H_2SO4 to pH<2, refrigerate	7 d	Nesolirization
Nitrate	P, G	100	Analyze as soon as possible or refrigerate	48 h	UV Spectrophometric
Nitrite	P, G	100	Analyze as soon as possible or refrigerate	none	Colorimetric
Organic Kjeldahl	P, G	500	Refrigerate; add H_2SO4 to pH<2	7 d	Macro-Kjeldahl Method
Odor	G	500	Analyze as soon as possible or refrigerate	6 h	Threshold Odor Test
Organic Compounds: Pesticides	G(S), TFE-lined	1,000	Refrigerate. add 1000 mg ascorbic acid/L if residual chlorine present	7 days until extraction; 40 days after extraction	Gas Chromatographic
Phenols	P, G	500	Refrigerate, add H_2SO4 to pH<2	7 days	Colorimetric: Direct Photometric Method
Oxygen Dissolved Electrode	G, BOD bottle	300	Analyze immediately	0.5 h	Electrometric
Winkler	G,BOD bottle	300	Titration may be delayed	8 h	Iiodometric (Azide Modification)
pH	P, G	100	Analyze immediately	0.5 h	Electrometric
Phosphorus	G(A)	100	For dissolved phosphate filter immediately; refrigerate	48 h	Digestion: Nitric Acid Sulfuric
Silica	P	150	Refrigerate, do not freeze	28 d	Colorimetric: Hetropoly Blue Method
Residues: * Total Nonfilterable (Suspended Solids)	P	1,000	None required	Analyze as soon as possible but within 24 hrs.	Volumetric
Total Filterable (Total Dissolved Solids)	P	1,000	Store at 4°C	Analyze as soon as possible but within 24 hrs.	TDS Dried @ 180°C
Sulphate	P, G	150	Refrigerate	28 d	Gravemetric
Sulphide	P, G	100	Refrigerate; add 4 drops 2N zinc acetate per 100 mL; add NaOH to pH>9	28 d	Methylene Blue Method
Taste	G	500	Analyze as soon as possible, refrigerate	24 h	Flavor Threshold Test
Temperature	P, G	——	Analyze immediately	Stat	
Turbidity	P, G	——	Analyze same day; store in dark up to 24 h, refrigerate	24 h	Nephelometric

Notes:

Refrigerate = storage at 4°C, in dark
P = plastic (polyethylene or equivalent)
G = glass
stat = no storage allowed

G(B) = glass, borosilicate
G(A) or P(A) = rinsed with 1 + HNO_3
G(S) = glass, rinsed with organic solvents
*Taken from EPA Victoria Report No. 95/79, rest from Standard Methods (18th ed.)

Table 1. Preservation and Method of Analysis for the Different Monitoring Parameters

REFERENCES

Australian and New Zealand Environment and Conservation Council and Australian Water Resources Council, National Water Quality Management Strategy: Policies and Principles - A Draft Reference Document, Melbourne,1992.

Barnes, D. and Wilson F., Chemistry and Unit Operations in Wastewater Treatment, Applied Science, London, 1978.

Brown, E., Skougstad, M. W., and Fishman M. J., Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gases: Techniques of Water Resources Investigations of the U.S. Geology Survey, Book 5, Chapter A1, Washington D.C., Superintendent of Documents, U.S. Government Printing Office, 1970.

De Zuane, John, Handbook of Drinking Water Quality: Standards and Controls, Van Nostrand Reinhold International Company Limited, New York, NY, 1990.

Environmental Management Bureau, The Philippine Environment in the Eighties, Department of Energy and Natural Resources, Quezon City, 1990.

Feachem, R.G., D.J. Bradley. H. Garelick, and D.D. Mara: Sanitation and Disease: Health Aspects of Excreta and Wastewater Management, Published for the World Bank by John Wiley and Sons, New York, 1983.

Hart, Barry T., Australian Water Quality Criteria, In An Ecological Basis for Water Resources (ed. W.D. Williams), Australian National University Press, Canberra, 1980.

Helawell, J.M., Biological Indicators of Freshwater Pollution and Environmental Management, Elsevier Applied Science, London, 1986.

Hunt, D.T.E. and Wilson, A.L., The Chemical Analysis of Water, Royal Society of Chemistry, United Kingdom, 1986.

Marquez, Jovita A., Hazardous Waste Management System in the Philippines, CIVL 9909 Project Report, School of Civil Engineering, UNSW, August 1995.

Metcalf and Eddy Inc., Wastewater Engineering Treatment, Disposal and Reuse, Mc Graw Hill, International Ed., CE Series, 3rd edition, 1992.

United States Environmental Protection Agency, Test Methods for Evaliuating Solid Waste Physical and Chemical Methods, SW 846, 1990.

MONITORING THE PERFORMANCE OF ANAEROBIC DIGESTERS AT HIGH LOADING RATES FOR FAILURE CONTROL AND OPTIMIZATION

NAOMI P. CARNAJE
Chemical Engineering Department, Central Philippine University

Abstract---*The anaerobic digestion process is of world wide significance for the treatment of highly concentrated wastes such as industrial and rural effluents, and sewage sludge. As its by product, a renewable fuel is produced. However, this process is known to be relatively unstable. Especially when loaded with high concentrations of organic material, volatile fatty acids (VFA) are produced rather than methane (CH_4) gas resulting in severe ecological, hygienic, and economic problems. The performance of a 1-liter laboratory anaerobic digester (CSTR) under high loading rates was investigated. The changes in the conversion efficiency of the digester, volatile fatty acid concentrations, H_2 partial pressure and pH were monitored at every step increase in the loading rate to determine the behavior of the digester near the maximum sustainable loading rate and under overloaded conditions. Some microbiological and chemical principles which explain why anaerobic digesters fail and how to prevent failure are likewise discussed. The findings reported in this study may be useful in the design of a control technique for the safe operation of anaerobic digesters.*

INTRODUCTION

A general interest in anaerobic digestion as a waste treatment and an energy producing process was first seen during the 1970s when in the midst of an oil crisis, worldwide research on renewable energy sources was encouraged and promoted (Wheatley, 1991). Methane, the by-product of the anaerobic process, is a useful alternative energy source. The production of biogas (a mixture of CH_4 and CO_2) from the anaerobic digestion of wastes could offer developing countries a unique opportunity to become energy self-sufficient. Specifically in Asia, rural anaerobic digestion has become popular because of the growing fuelwood deficiency (Coombs, 1991). Biogas is also known to be a cleaner and a more environmentally friendly energy source than conventional energy (e.g coal and other forms of fossil fuels). Therefore, the use of biogas as an alternative energy source represents a sustainable solution to the present problem of fuel deficiency and environmental degradation.

In developed countries where oil and other fossil fuels can be used more economically than the methane gas, anaerobic digestion is increasingly used for waste treatment rather than for energy production. However, despite the reported success and wide application of anaerobic digestion, industries are still reluctant to employ this process for waste treatment. Instead, the wastes are treated aerobically, which means that a relatively expensive process (high energy cost due to aeration and sludge treatment) is preferred to one which can be operated at low cost (energy self-sufficient). The main reason for this is the reputation of the process for instability and the difficulty in failure control.

Several laboratory and pilot scale studies, as well as full-scale digester operations indicated that reduced performance and failure in anaerobic digesters are caused by organic overloading (Canovas-Diaz & Howell, 1988; Kennedy, 1985; Chynoweth, 1994). This problem has been demonstrated in several of the digesters at the Western Australia Headworks and Treatment Plant, Woodman Point, Perth, Western Australia. A number of digester failures in the treatment plant had been recorded from 1989 to 1994 resulting in long shutdown periods and severe economic loss. Instabilities in the operation of anaerobic digesters (biogas digesters) in the Philippines have been reported. The 1994 Non-conventional Energy System Census conducted by the Central Philippine University - Affiliated Non-conventional Energy Center (CPU-ANEC) in the provinces of Iloilo, Antique, Aklan, Capiz and Guimaras revealed that out of thirty four (34) biogas digesters installed in these provinces, twenty two (22) are inoperational.

To prevent digester failure due to organic overloading, the rate of feed addition is frequently applied well below the maximum sustainable loading rate of the digester. Such an operation is not always desirable, especially when a process is expected to perform competitively and cost-effectively. To make the process more efficient and economical, the loading rate of the digester could be maximized. However, feeding the digester at high loading rates increases the risk of overloading and consequently results in digester failure.

In order to ensure successful operation of anaerobic digesters at high loading rates, constant monitoring of process parameters is necessary. Several studies have reported the importance of process indicators such as VFA, alkalinity, pH, gas production and composition, H_2, volatile solids and COD (chemical oxygen demand) in the monitoring of digester performance (Switzenbaum et al., 1990). However, few studies have investigated the changes in the above parameters at high loading rates and the behavior of the digester at its maximum sustainable loading rate.

Objectives of this study

This study was aimed at determining useful control parameters in the anaerobic digestion of organic wastes. The specific objectives were:

1. to monitor the changes in various process parameters (methane production rate, VFA concentrations, H_2 concentration and pH) during step increases in the loading rate.
2. to investigate digester behavior at high loading rates and at overloaded conditions.
3. evaluate digester performance at the maximum sustainable loading capacity of the digester.
4. To provide information on why anaerobic digesters fail and how to prevent failure.

REVIEW OF THE ANAEROBIC PROCESS

Stages of methane conversion

In anaerobic digestion, the organic substances in the waste are converted to methane (CH_4) and carbon dioxide (CO_2) by different groups of interacting bacteria. The methane conversion is a complex process involving several consecutive and parallel reactions (Fig 1).

The first stage is hydrolysis. Complex organic compounds (proteins, cellulose, lipids) are hydrolysed by extracellular enzymes into simpler compounds (sugars) small enough to allow their transport across the cell membrane of the bacteria. The enzymes can be produced by both facultative and strictly anaerobic bacteria.

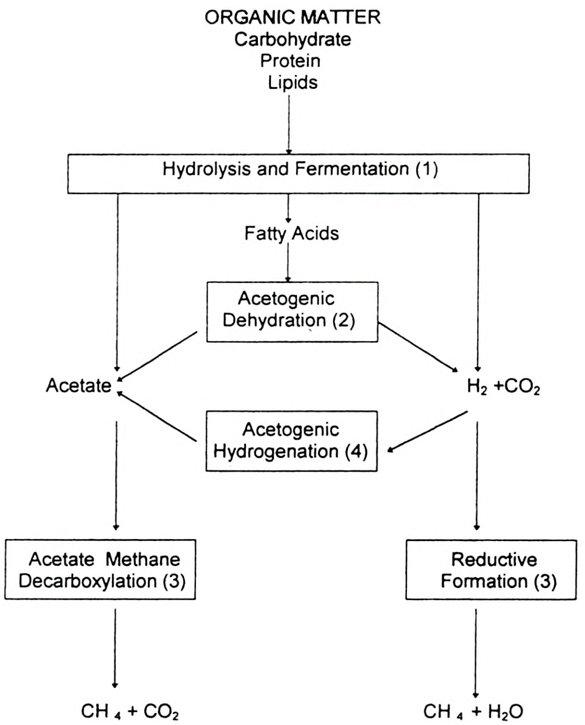

Figure 1. Schematic representation of the complete anaerobic degradation of organic matter showing the general pathways and the three major metabolic groups of bacteria: 1) fermentative bacteria; 2) obligate hydrogen producing acetogenic bacteria; 3) homoacetogenic bacteria (McInerbey & Bryant, 1981).

The second stage is acid fermentation or acidogenesis. The simpler compounds from the hydrolysis of polysaccharides are fermented to volatile fatty acids (VFAs) such as acetate, propionate, butyrate, alcohols, CO_2 and H_2 and some lactic acid by the fermentative bacteria.

The third stage is acetogenesis. The more reduced products such as propionate and butyrate are oxidized to acetate, CO_2 and H_2 by syntrophic bacteria called obligate proton-reducing (i.e. H_2-producing) acetogens or obligate proton-reducing (i.e. H_2-producing) organisms to acetate, CO_2 and H_2.

The final stage is methanogenesis. The methanogenic bacteria utilize the H_2 produced by acidogenic and acetogenic bacteria for the reduction of CO_2 to CH_4. Some species cleave acetate to CO_2 (known as aceticlastic methanogenesis) and CH_4.

In order for the digester to operate under stable and optimum performance, there must exist a balanced microbial population in the reactor. An imbalance in the activity of the acid forming bacteria and the methane forming species can lead to the accumulation of the volatile fatty acids and eventually inhibition of the digestion process.

Thermodynamic effects on methane fermentation

According to thermodynamics, the spontaneity of a reaction is determined by its exergonicity (-ΔG). Table 1 shows the equations and standard free energy changes involved in the anaerobic degradation of organic matter. It is shown that the H_2-consuming methanogens play a very important role in the the conversion of the acid products to CH_4. Studies on the metabolic interactions between the acid-producing bacteria and the H_2-consuming methanogenic bacteria indicate that the rate at which the H_2 concentration is kept low determines the stability of the digestion process (Wolin, 1975, Kaspar and Wurhmann, 1978, Mah and Boone, 1982). At high partial pressure, the production of propionate, butyrate and other reduced products are favored instead of acetate production and methane conversion.

The H_2 concentration also regulates the degradation of the reduced fermentation products by the obligate hydrogen producing bacteria (OHPB) to acetate, H_2 and CO_2. At standard partial pressure of H_2, the degradation of propionate and butyrate are inhibited (+ G, equations 2 and 3 Table 1.1). The degradation of butyrate or propionate is not energetically favorable until the partial pressure is lowered to about 2 x 10^{-3} or 9 x 10^{-5} atm, respectively (McInerney & Bryant, 1981). In order for the degradation to proceed, the low H_2 level must be maintained in the system through H_2 removal, a task accomplished by the H_2 consuming methanogenic bacteria. Therefore, in ecosystems where methanogens are effectively utilizing H_2, considerably less propionate and butyrate are produced.

Kinetic Factors Influencing Digester Efficiency

Process kinetics play a central role in the development and operation of anaerobic treatment plants. Since the anaerobic digestion process is composed of a sequence of reactions, one step usually proceeds at a rate lower than the other steps. Lawrence (1971) proposed that for anaerobic digestion processes, the rate limiting step is that step which will cause process failure to occur under conditions of kinetic stress. Methanogenesis is

Reactions	ΔG, (kJ/reaction)
(1) $C_6H_{12}O_6 + 2\ H_2O \rightarrow 2\ CH_3COOH + 2CO_2 + 4H_2$	- 342.0
(2) $CH_3CH_2CH_2COO^- + H_2O \Leftrightarrow 2\ CH_3COO^- + H^+ + H_2$	+ 48.1
(with methanogens)	- 102.4
(3) $CH_3CH_2COO^- + 3\ H_2O \Leftrightarrow CH_3COO^- + HCO_3^- + H^+ + 3\ H_2$	+ 76.1
(with methanogens)	- 39.4
(4) $4\ H_2 + 2HCO_3^- + H^+ \Leftrightarrow CH_3COO^- + 4\ H_2O$	- 104.6
(5) $CH_3COO^- + H_2O + \Leftrightarrow CH_4 + HCO_3^-$	- 30.0
(6) $4\ H_2 + CO_2 \rightarrow CH_4 + 2H_2O$	- 135.6

Table 1. Equations and Standard Free-Energy Changes Involved in the Anaerobic Degradation of Organic Matter (McInerney and Bryant 1979; Zeikus, 1980; Zehnder & Wurhmann, 1977)

considered the rate limiting step in the digestion of soluble organics (e.g. sucrose), (Ghosh and Poland, 1974; Novak and Carlson, 1970). For insoluble polymers, hydrolysis is regarded as the rate limiting step (Ghosh et al., 1974).

Hydraulic retention time (reactor volume/feed flow rate) is one of the most important operational factors affecting the efficiency of an anaerobic digester (McInerney and Bryant, 1981; Grady and Lim, 1980, Dague, et al, 1970). As the retention time is increased in a system fed with a substrate of constant concentration, a higher percentage of the organic matter is destroyed but less organic matter is available. Thus, the rate of methane production may decrease. Conversely, when the hydraulic retention time is shortened by increasing the feed flow rate, the CH_4 production rate may increase. However, the liquid throughput might exceed the growth rate of the bacteria and result in the washout of the slow growing methanogens (hydraulic overloading).

The organic loading rate is another important factor to consider in the operation of anaerobic digesters. The loading rate can be increased at a given RT by feeding more concentrated feed or by shortening the RT at a given feed concentration. High loading rates increase the methane production rate, but in effect, decrease the % solids destruction of the waste (McInerney & Bryant, 1981).

MATERIALS AND METHODS

Source of Biomass. The biomass used in this study was a granular sludge obtained from a hybrid anaerobic digester at Swan Brewery, Perth, Western Australia.

Synthetic substrate C-source (g/L): D-glucose, 24.5; yeast extract, 1.0; tryptone, 1.0; Basal nutrients: NH_4Cl, 1.07; $MgCl_2.6H_2O$, 1.02; $CaCl_2.2H_2O$, 0.01; KCl, 0.52; Na_2SO_4, KH_2PO_4, 0.30; $NaHCO_3$, 2.10; Trace metal solution (mM): HCl, $FeCl_2.4H_2O$ 0.2; $CoCl_2.6H_2O$, 0.006; $MnCl_2.4H_2O$, 0.0033; $ZnCl_2$, 0.006; H_3BO_3, 0.0016; $Na_2MoO_4.2H_2O$, 0.0049; $NiCl.6H_2O$, 0.0025; $CuCl_2.2H_2O$, 0.006. One liter stock solutions were prepared and autoclaved for one hour (15 psia, 110 °C) to maintain sterile condition in the feed medium. The trace elements (5 ml) and the $NaHCO_3$ buffer (25 ml) were added into the feed bottle through a 0.2 m sterile filter. In the case where a more concentrated feed was used, the amounts of basal nutrients, trace elements and buffer solution were increased proportionally with the feed concentration. The pH of the feed was adjusted to 7-7.5 by adding NaOH before the start of each experiment.

Experimental Set-up. A 1.3-L Braun Biolab anaerobic digester (Fig 2) was filled with 1.0 L of active anaerobic sludge (13 g/L of dry suspended solids) leaving a 0.3 L gas volume. The reactor temperature was maintained at 35 °C by immersing the reactor in a water bath thermostatically controlled by a Thermo Mix MM Braun heater. The sludge liquid was kept well mixed by a flat blade impeller stirring at 300 rpm.

The feed to the reactor was supplied by a two-channel peristaltic pump (EYELA Micro Tube Pump MP-3) calibrated at the commencement of the experiments. The loading rate was regulated by a digital timer. The on-time setting of the timer was varied according to the changes in the loading rate while the off-time setting was maintained constant. The amount of feed entering the reactor was measured by a Sartorius electronic balance (BA 4100 Goettingen, Germany).

The biogas produced during digestion passed over NaOH pellets and through concentrated solutions of NaOH to remove the CO_2 gas. The volume of the gas produced was measured continuously by weighing the equivalent mass of water displaced by the gas from the digester. The Sartorius balance was interfaced to an IBM-PC computer for continuous monitoring of the volume of gas produced.

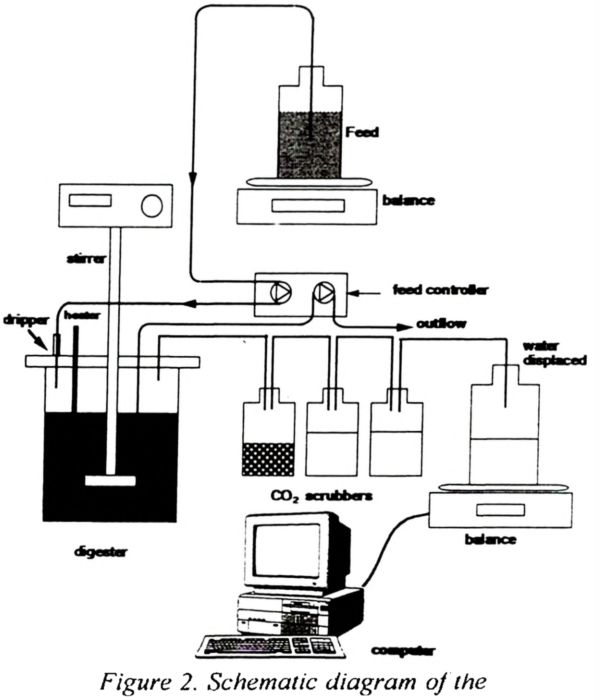

Figure 2. Schematic diagram of the experimental setup

pH. About 5 ml of sample was withdrawn from a sampling port on top of the digester and analysed for pH. The pH of the sludge and the feed were measured with Hanna HI 8424 Microcomputer pH meter.

Volatile Fatty Acid (VFA). Samples of reactor mixed liquor were prepared for volatile fatty acid determination by centrifuging (in a microfuge at 15,000 rpm) 1 ml of mixed liquor for 10 minutes to remove suspended solids. The supernatant was acidified by the addition of 0.5 % v/v concentrated phosphoric acid to extract all the free VFA as well as to suppress bacterial activity. The samples were analysed for the presence of volatile fatty acids by Varian 3300/3400 gas chromatography. The operating parameters for gas chromatograph were as follows: Column:Glass, 1.8 m x 2 mm ID, Packing: Poropack QS,80/100mesh, Column Temperature: 190°CarrierGas: N_2 carrier gas flow rate : 12 ml/min, Injection Temperature: 250 °C, Sample Volume: 1 l, Detector: Flame Ionisation Detector, Detector Temperature: 250 °C Detection Limit: 0.1 mM.

Standards with known concentrations of acetic acid, propionic acid, and butyric acid 0.5-20 mM were included at regular intervals during volatile fatty acid analysis to calibrate the instrument. The samples were stored frozen at -20 °C in cases where volatile fatty acid analysis could not be carried out at the time of sampling.

Hydrogen Concentration in the Biogas. The hydrogen content of the biogas was determined using a Trace Analytical, Reduction Gas (Stanford, CA) model RGA3. The analyser operated under the following conditions: Column Temperature: 106 °C, Detector Temperature : 228 °C, N_2 carrier gas flow rate: 10 ml/min, sample size: 0.5 ml. The H_2 detection was based on H_2 reduction of HgO to Hg vapour, which was measured through a UV light detector. The chromatograph was recorded using Omniscribe chart recorder and H_2 concentrations of both gas sample and the H_2 standard were determined from the chromatogram via peak height analysis. The detection limit is ± 10 ppb.

RESULTS AND DISCUSSION

Determination of the maximum sustainable loading rate of the digester

The loading rate of the digester was increased by step increments of 20 to 40% to allow the reactor to operate at high organic and hydraulic loading rates (Fig. 3a). The response of the digester towards the step increases was monitored in terms of gas production rate, VFA concentration, and H_2 partial pressure inorder to assess digester performance prior to and after reaching the maximum sustainable loading rate.

As expected, the increase in the loading rate was reflected by the increase in the methane production rate (Fig. 3b, 0 to 36h). This trend was observed until at 19 mmoles glucose/L d (HRT = 8 days), a maximum gas production rate of 52.7 mmoles CH_4/L d (or 1.42 L CH_4/L d) was obtained. During this period, the acetic and propionic acids increased from concentrations below 1 mM to about 2 mM (Fig. 3d, 36h). This indicated that the balance between the acid production and methane formation reactions had been slightly disturbed. To determine whether the loading rate could be further increased without resulting in acid accumulation, the feed flow rate was raised to 22.9 mmoles of glucose/L d, (HRT=6 days). This time, the increase in the loading rate did not result in a further increase in the methane production rate but instead resulted in the drop of the conversion

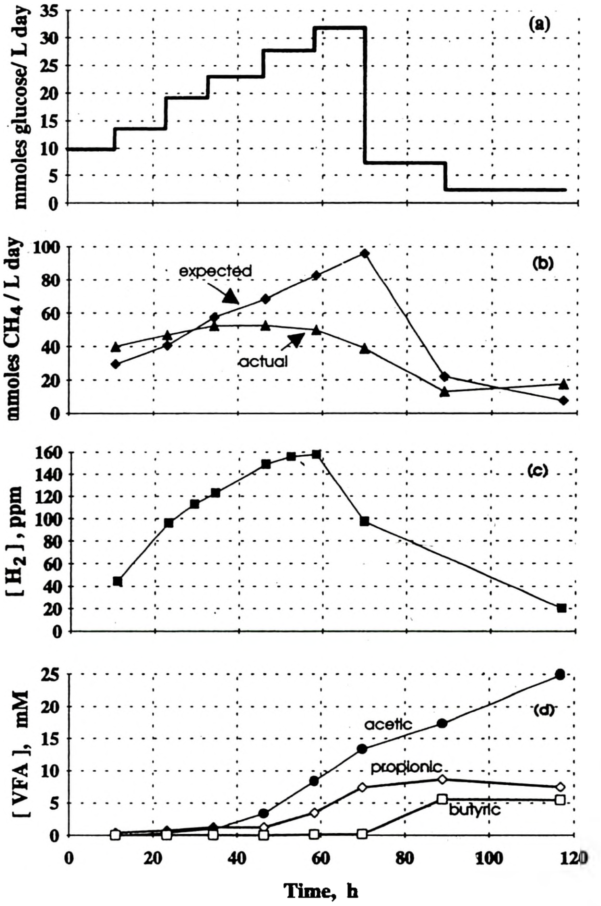

Figure 3. Response of the laboratory digester to continued increases in the loading rate using low feed concentration of 24.5 g/L d.

efficiency from 76% to 69% (Fig 3b, 48 h). This signified an accumulation of organic intermediates which was confirmed by an increase in the propionic acid concentration by almost threefold in twelve hours and small incrérases in the acetic and butyric acids (Fig. 3d, 36h). Although the acid concentrations were still within the range reported for stable digesters, the fact that the VFA concentrations were increasing was a clear proof that digester imbalance had occurred and that the risk of failure had increased. The increase in the VFA concentration and the failure of the digester to increase the methane production rate proportionally with the loading rate indicated that the digester had reached its maximum sustainable loading rate at 19 mmoles glucose/L d.

Digester behavior above the maximum sustainable loading rate

The loading rate was increased above the maximum sustainable loading rate to 32 mmoles glucose/L day (HRT = 4 days) to determine the response of the digester to critical loading conditions (Fig 3b, 59 to 72 h). This increase in the loading rate resulted in a 36% decline in the rate of methane production. Within twelve hours after the increase in the loading rate, the propionic and acetic acid concentrations rose to 13 mM and 7 mM respectively.

Several authors reported that an imbalance in the microbial population during the anaerobic process is brought about by high concentrations of H_2 (Kaspar and Wuhrmann, 1978; McInerny and Bryant, 1981; Wolin, 1974). The glucose synthetic waste used in this experiment is a readily degradable substrate, thus the continued increases in the loading rate consequently resulted in the gradual increase in the H_2 concentration. The build up of H_2 from 40 ppm to 160 ppm within the 60 hours digester run (Fig 3c) is a result of a relative increase of the bacterial hydrogen production compared to the H_2 consumption.

According to the thermodynamics of the anaerobic process, the increase in the H_2 concentration would shift the electron flow during fermentation towards the formation of the more reduced products such as propionate and butyric acids rather than acetic acid. McInerney and Bryant (1981) reported that a hydrogen partial pressure of 95 ppm to 2000 ppm could inhibit propionate and butyrate degradation respectively. Due to the accumulation of the propionic, acetic and butyric acids in this experiment, the pH dropped from 6.5 to 5.1. Since the methanogenic bacteria were found to be very sensitive to high acidity (McCarty, 1964), the drop in pH resulted in the decline of the methane production rate.

The increase of the loading rate to 27 mmoles glucose/L day (HRT= 5 days) and further to 33 mmoles glucose/L day(HRT = 4 days) could have caused the washout of the slow growing methanogens (hydraulic overloading). Grady (1980) reported that for a constantly stirred tank reactor, a HRT < 10 days could cause hydraulic overloading. The perceived hydraulic overloading in this experiment resulted in the accumulation of mainly propionic, acetic and butyric acids, with propionic acid as the main acid constituent. This result agreed with the hydraulic overloading experiment undertaken without pH control by Canovas-Diaz and Howell (1988) in a downflow fixed film anaerobic reactor. He reported concentrations of 3000 mg/l of propionic, 2000 mg/l of acetic and 400 mg/L of butyric after a sharp hydraulic overloading.

The effect of increased feed concentration on digester performance

1) At a feed concentration of 48 g glucose/L.

The feed concentration was doubled to determine if the maximum sustainable loading rate is affected by the concentration of the waste(Fig 4a, 0 to 62h). As expected, the increase in the loading rate was reflected by the increase in the methane production rate. This trend was observed until the loading rate was increased to 19 mmoles glucose/L day (HRT=14 days). The loading rate of 19 mmoles glucose/L d could already have been high, for at this rate, acetic acid started to accumulate and the hydrogen concentration already increased above 100 ppm (Fig 4c and d, 45 to 62 h). It appeared therefore that the maximum sustainable loading rate was about 19 mmoles glucose / L d (HRT = 14 days). In contrast to the results from previous experiment, acetic acid showed a greater tendency to accumulate than propionic acid. Its concentration increased sharply from 1.9 mM to 6 mM within 20h whereas only small increases in the propionic and butyric acid concentrations were evident. Acetic acid predominated in this experiment because during anaerobic fermentation, the reducing equivalents are firstly channelled towards the formation of acetate, H_2 and CO_2 followed by the formation of propionic and butyric acids (Mah, 1980).

The increase of the loading rate to 24 mmoles glucose/L d (HRT=11 days) resulted in a decline in

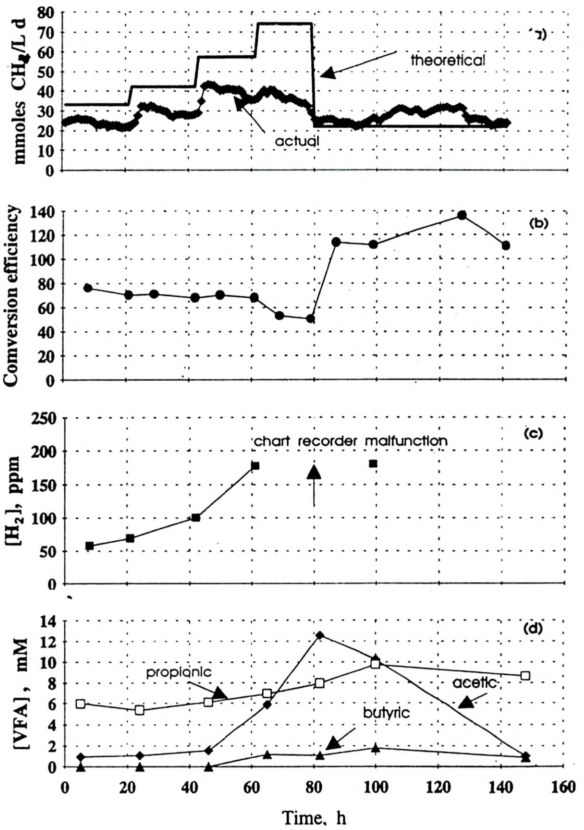

Figure 4. Response of the laboratory digester to continued step increases in the loading rate using medium feed concentration of 48 g/L.

the methane production rate (Fig. 4b, 62 - 80 h). This indicated that the maximum sustainable loading rate of the digester was exceeded at 24 mmoles glucose/l day. A clear overloading of the digester was evident at this rate for during this period, the hydrogen concentration rose from 100 to 179 ppm (Fig. 4c), indicating a higher bacterial H_2 production rate than the H_2 consumption rate. The increase in VFA concentrations resulted in the drop of pH from 6.5 to 6.0. Consequently, the methane production rate and the conversion efficiency decreased.

2) At an increased feed concentration of 63g glucose/L.

The feed concentration was increased to 63g glucose/L to determine whether or not a further increase in the feed concentration would give the same maximum sustainable loading rate found in the previous experiments (24 g glucose/L and 48g glucose/L). The methane production rate continually increased when the loading rate was increased stepwise from 9.5 mmoles glucose/L day to 19 mmoles glucose/L day (HRT =18 days, Fig. 5a). A further increase in the loading rate to 23 mmoles glucose/L day (HRT =15 days) resulted in an only 8% increase in the methane production rate and a drop in the conversion efficiency from 70% to 65%. A clear increasing trend in the hydrogen concentration (greater than 100 ppm) was evident as the loading rate was increased (Fig. 5c). The continued increase in the H_2 partial pressure and its correlation with the increasing VFA concentration indicated that H_2 could be a good process indicator in anaerobic digesters. In this experiment, an obvious accumulation of the acetic acid when the loading rate was increased from 15 to 19 mmoles glucose/l day again indicated that the maximum sustainable loading rate of the digester had been reached at 19 mmoles glucose/l day. Moreover, the sharp increase in the acetic acid concentration from 5 mM to 15 mM when the loading rate was further increased to 23.1 mmoles glucose/L d signified an organic overloading which resulted in acetic acid accumulation only (Fig. 5d).

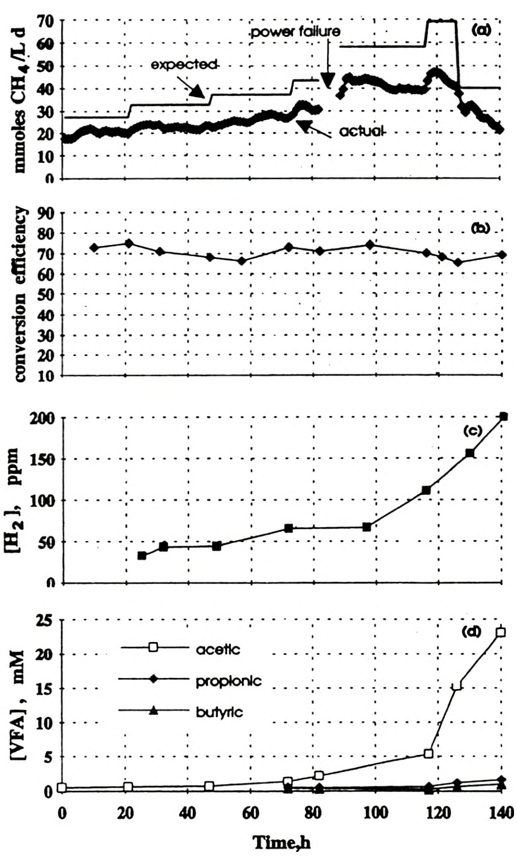

Figure 5. Response of the laboratory digester to continued increases in the loading rate using high feed concentration of 63 g/L.

Comparison of digester performance at different feed concentrations

The results of the three experiments conducted at similar organic loading rate but different feed concentrations indicate that the maximum sustainable loading rate of the digester is dependent on the amount of organic load added. On the other hand, it appeared that within the loading rates tested, the maximum sustainable loading rate of the digester is independent of the hydraulic retention time. In the three experiments, the maximum loading rate was found close to 19 mmoles glucose/L d (VFA concentrations < 6 mM) despite the differences in the HRT.

The differences in the type of overloading that occurred after the maximum sustainable loading rate was exceeded demonstrate the effect of feed concentration and HRT on the performance of the digester. The propionic, acetic and butyric accumulation found in the first experiment could have been due to hydraulic overloading. The observed increases in acetic, propionic and butyric acids during an organic overloading in the second experiment using a more concentrated feed (48 g glucose/L) is a typical response of an anaerobic reactor to organic shockload (Kennedy and van den Berg, 1982; Cohen et al., 1980). However, the predominant acetic acid accumulation during the organic overloading at the feed concentration of 63 g glucose/L is in contrast with the observations of Barnes et al.(1984), who reported that the main acid constituent during organic overloading is propionic acid. This contradiction reflects differences in the adaptation of the reactor's microbial populations, the type of waste used and the reactor configuration.

Digester recovery after a loading rate reduction

Towards the end of the experiments, the digester was allowed to recover by decreasing the loading rate. In the first experiment, feed reduction was not successful in recovering the digester since the biomass had been severely damaged due to the accumulation of propionic, acetic, and butyric acid (Fig 3d). In the second experiment, digester recovery was attempted by reducing the loading rate by about 2/3. This successfully prevented the digester from acidifying and failure (Fig 4d). Acetic acid was readily removed, although propionic and butyric acids showed difficulty in degrading. The methane gas was continually produced at a rate higher than what was expected, obviously because of the undegraded organics from the previous load. In the third experiment, the loading rate was decreased by 30% to prevent a further increase in the acetic acid concentration. In this case, digester overloading was not prevented. In spite of the feed reduction, the methane production rate continued to decline (Fig 5a) This is very interesting, as there was no real reason for the gas production to decrease. A pH of 6.0 was not too low to cause souring. Furthermore, propionic acid did not accumulate and the acetic acid concentration (15 mM) was just a little higher than its concentration at the time overloading occurred in the previous experiment. One plausible reason could be that the reduced loading rate (14 mmoles glucose/L d) was still high for the biomass. It should be noted that the acetic acid concentration continued to increase to about 23 mM even after the lowering of the feed. In this case, feed termination was definitely necessary for digester recovery.

CONCLUSIONS AND RECOMMENDATIONS

Based on the observations presented, the following conclusions can be drawn:

*The relationship between the gas production rate to the loading rate could be a useful indicator of digester performance especially to biogas operators who consider productivity as an important aspect in digester operation and optimization. As long as gas production rate increases proportionally with the loading rate, the amount of feed to the reactor could be further increased, thus maximizing waste addition. Conversely, the unproportional relationship between the gas production rate and the loading rate could signal that the sustainable loading rate of the digester had been exceeded and that an imbalance in the microbial activity is likely to occur.

*Organic overloading could be confirmed by the following indicators: 1) an increase in the hydrogen level above 100 ppm, 2) a rapid rise in the concentrations of acetic acid (about 12 mM), and pronounced increases in propionic and butyric acid concentrations, 3) a drop in pH below 6.0; 4) a sharp decrease in the methane production rate and consequently a drop in the digester conversion efficiency below 70 %.

*H_2 concentration could play an important role in the development of a process control technique for the safe operation of anaerobic digesters An early sign of digester imbalance could be detected through constant monitoring of the changes in the hydrogen concentration. Its usefulness could be further

enhanced when monitored together with conversion efficiency.

*The acetate concentration is another useful indicator of process upsets in anaerobic digestion, especially during organic overloading.

*The concentration of the feed influences the type of acid that predominates in the reactor and within the loading rates tested was independent of the hydraulic retention time.

*Further acidification in the reactor which is slightly overloaded could be prevented by an immediate reduction in the loading rate. In severe cases, feed termination is definitely necessary. This provides a relevant information for the development of a control technique that could safely operate anaerobic digesters under high loading rates.

*The feed used in the experiments was glucose, an easily digestible substrate of known composition. As most industrial and agricultural wastes contain high concentration of proteins, fats, cellulose, etc, the results presented in this study could be verified in large digesters (pilot scale, full scale) degrading different types of wastes. The results of the experiments have shown that VFA measurements could reliably assess the performance of anaerobic digesters. However, the monitoring of this parameter is often not available on-line and needs highly trained staff and expensive equipment. Further studies on the usefulness of control parameters which can be monitored on-line (i.e. gas production rate, H_2 concentration) could be conducted for digester control and optimization.

ACKNOWLEDGMENT

This paper is an excerpt from the author's thesis for the degree of Master of Philosophy in Biotehcnology at Murdoch University. N. Carnaje was supported by an AIDAB scholarship provided by the Australian Government. The supervision of Dr. Ralf Cord-Ruwisch, Murdoch University is gratefully acknowledged. The financial support of Central Philippine University and the technical assistance of Dr.Grahame Strong, Dr. Tom Mercz and Choon Hoh during the conduct of the research are also acknowledged.

REFERENCES

Barnes, D., Bliss, P.J., Gould, B., Kuo, E.M. and Robins, K. (1984). Influence of organic shock loads on the performance of an anaerobic fluidized bed system. *Proc. Ind. Waste Conferences*. 38, 715-723.

Canovas-Diaz, M. and Howell, J.A. (1988). Downflow fixed-film anaerobic reactors *Wat. Res*. 22, 529-536.

Chynoweth, D.P., Svoronos, S.A., Lyberatos, G.,Harman,J.L., Pullammanappalil, P., Owens, J.M., and Peck, M.J.(1994). Real-Time expert system control of anaerobic digestion. *Wat.Sci.Tech*. 30, 21-29.

Cohen, A., Breure A.M., Andel, J.G., Eursen, A. van (1980). Influence of phase separation on the anarobic digestion of glucose 1: maximum COD-turnover rate during continuous operation. *Wat. Res*. 14, 1439-1448.

Coombs, J and Alston, Y.R. (1988). The potential for recovery of energy from solid wastes using fabricated digester systems. In *Landfill Gas and Anaerobic Digestion of Solid Waste*, ed. Y.R. Alston and G.E. Richards. UK Department of Energy, London, pp, 454-466.

Dague, R.R. (1970). Solids retention in anaerobic waste treatment systems. *Journal of Water Pollution Control Federation,* 42, 29-46.

Ghosh, S. and Poland, F.G. (1974), Kinetics of substrate assimilation and product formation I anaerobic digestion, *Journal of the Water Pollution Control Federation*, 46, 748-759.

Grady,C.P.L. Jr. and Lim,H.(1980) *Biological Wastewater Treatment, Theory and Applications*, Marcel Dekker, Inc, New York.

Gujer, W., Zehnder, A.J.B. (1983). Conversion processes in anaerobic digestion. *Wat. Sci. Technol*. 15, 127- 165.

Kaspar, H.F. and Wuhrmann, K. (1978). Product inhibition in sludge digestion. *Microbial Ecology* 4, 241-248.

Kennedy, K.J. and Berg, L. van (1982a) Effect of temperature and overloading on the performance of anaerobic fixed-film reactors. *Proc. Ind. Waste Conferences* 36, 678-685.

Mah, R.A., Boone, D.R. (1982). Methanogenesis and methanogenic partnerships. *Phil. Trans. R.Soc.* London 297, 599-616.

McCarty, P.L,, (1964). Anaerobic waste water treatment fundamentals. *Public Works*, 95, 123-126.

McInerney, M.J., and Bryant, M.(1981). Basic principles of bioconversions in an anaerobic digestion and methanogenesis. In: SS Sofer, RZ Oskar (eds) *Biomass conversion process for energy and fuel*. Plenum Publishing Corp, 277-

295.

McCarty, P.L., 1971. Energetics and kinetics of anaerobic treatment. *Adv. Chem. Series.* 105, 91- 107.

Switzenbaum, M.S., Giraldo-Gomez, E., Hickey, R.F. (1990). Monitoring of the anaerobic methane fermentation process. *Enzyme Microb. Technol.* 12, 722-730.

Wheatley, A. (1991) *Anaerobic digestion: a waste treatment technology*, Elsevier Science Publishers Ltd., England.

Wolin, M.J., (1975). Interactions between H_2-producing and methane-producing species, In H.G. Schlegel, G. Gottschalk, and N Pfening (ed.) *Symposium on microbial production and utilization of gases.* E. Goltz, Gottingen, Federal Republic of Germany.

Zehnder, A.J.B., and Wuhrmann, K. (1977). Physiology of a methanobacterium strain AZ. *Arch. Microbiol.* 111, 199-205.

20. Zeikus, J.G. (1980) Microbial population in digesters. *Anaerobic Digestion.* Stafford, D.A., Wheatley, B.I. and Hughes, D.E. (eds.), Applied Sciences Publisher Ltd., London, pp.61-87.

THE NON-CONVENTIONAL ENERGY SYSTEMS (NES) CENSUS OF PANAY AND GUIMARAS

JERIEL G. MILITAR
Head, Technology Division, CPU-Affiliated Non-conventional Energy Center

Abstract---*This paper presents in brief selected results of the census of non-conventional energy systems (NES) of Panay and Guimaras. The census was conducted by the Central Philippine University- Affiliated Non-conventional Energy Center (CPU-ANEC) as part of the National Census of NES mandated by the Department of Energy (DOE) through its Non-Conventional Energy Division (NCED). One important finding shown by the results of the census is that biomass is the greatest contributor of non-conventional energy in Panay and Guimaras. Another important finding which is somewhat already expected, is that wind pumps proliferate in Iloilo. However, many of these are inoperational due to technical failure and a good number had been damaged by strong typhoons. Findings like these can serve as useful inputs in the formulation of area-based energy plans to effectively promote the widespread use of non-conventional energy. Furthermore, other government and private institutions, individual researchers, project implementors and entrepreneurs can also make good use of these findings as well as other additional information that can be gleaned from the results of the census. The complete results are available at the CPU-ANEC office to interested parties upon request.*

INTRODUCTION

The Department of Energy (DOE), in its effort to increase the contribution of non-conventional energy in the total energy mix of the country in order to help lessen the country's dependence on imported fuel oil and promote environment-friendly energy systems, decided to strengthen its non-conventional energy program which is being implemented through its Non-Conventional Energy Division (NCED).

One of the initial steps undertaken towards this end was the conduct of the National Census of Non-conventional Energy Systems (NES). The main objective of the census was to establish a database of baseline figures on the extent of NES utilization in the country. This baseline database will provide information that can serve as useful inputs in the formulation of future non-conventional energy programs. Such a database can also be a source of helpful information even for other non-energy-related undertakings.

DEFINITION OF TERMS

Non-conventional or ***renewable energy*** is energy derived from resources whose utilization are not as widespread and as large-scale as conventional ones such as oil, large hydro, and geothermal. These non-conventional energy resources include wind, solar, biomass (vegetal and animal matters such as wood, rice hull, bagasse, animal wastes, etc.), ocean (current, wave, thermal) and microhydro (small streams or waterfalls).

Non-conventional energy systems (NES) refer to devices or systems that convert these non-conventional energy resources into useful energy forms. NES are usually characterized as site-specific, modular, small scale and decentralized. NES covered in the census are enumerated and defined in the following paragraphs.

Wind energy conversion systems (WECS) convert energy in the wind into a rotational motion which is used directly for mechanical application as in *wind pumps*, or converted further to electricity for more varied applications as in *wind turbine generators*.

Solar energy systems are of two types: those that directly use the heat energy from the sun for heating or drying purposes like *solar dryers (excluding concrete pavements)* and *solar water heaters*; and those that directly convert sunlight into direct current (DC) electricity using solar cells as in *Photovoltaic or PV systems.*

Biomass energy systems convert stored energy in biomass into heat or another fuel form either by direct combustion as in *stoves, ovens, kilns, boilers, dryers*, or by controlled decomposition as in *biogas* *digesters.*

Microhydro systems convert energy from moving or falling water using a water wheel or a turbine for direct small-scale mechanical application and/or electricity generation.

METHODOLOGY

The Affiliated Non-conventional Energy Centers (ANECs), established by NCED in nineteen (19) state and private universities and colleges strategically located in all the regions throughout the country were mandated to conduct the census in their respective areas of coverage. NCED provided the ANECs with an initial list of NES installations found in their areas of coverage. This list, though not complete and up-to-date, provided a document to start with. The ANECs verified the existence of the listed installations, updated the list and used the same as a starting point. It was left to the individual ANECs to decide on how to identify additional installations not found in the initial list.

Census questionnaires (one per NES type), the enumerator's manual and the table formats to be used in reporting the results were provided by NCED to ensure uniformity of collected data and reported results, but the ANECs were given the freedom to formulate their own strategies in implementing the census.

Most of the ANECs started conducting the survey during the third quarter of 1994 and have completely covered all the provinces in their areas by the end of 1995, but in some areas, especially in areas where the ANECs are newly established, the census is still ongoing.

CPU-ANEC's coverage included the provinces of Aklan, Antique, Capiz, Iloilo and Guimaras. The census of these provinces was started in Iloilo in October 1994. Eight full time enumerators mostly fresh engineering graduates, were fielded out and were able to cover all the five provinces in three months. The help of municipal planning officers and barangay officials were solicited by the enumerators in identifying additional NES installations in their respective municipalities and barangays. After the data gathering, data from the questionnaires were then entered into a computerized database using the NESCON program, also provided by NCED. A copy of the database files created by the program and the printed results in the prescribed table formats were then submitted to NCED for aggregation at the national level.

RESULTS AND OBSERVATIONS

The complete results of the census are presented in seven (7) tables prescribed by NCED as follows: Table 1, Contribution by resource by province/ municipality (in BFOE); Table 2, Contribution by resource by province/municipality (in Percent); Table 3, Contribution by technology by province/ municipality (in BFOE); Table 4, Contribution by technology by province/municipality (in Percent); Table 5, NES installation by province/ municipality by capacity; Table 6, Number of NES installation by province/municipality; and Table 7, Non-operational NES installations.

These results are available at the CPU-ANEC office, College of Engineering, Central Philippine University, Jaro, Iloilo City. Census results for other areas in the country are also available at the concerned ANEC offices while national level results are available at the NCED office, PNPC Complex, Fort Bonifacio, Makati City.

Only selected results for Panay and Guimaras are gleaned out from these tables and presented here together with some important observations.

Noncon Energy Contribution by Resource

Table 1 shows that biomass resources (manure, bagasse, ricehull, cocohusk, cocoshell, wood/ woodwastes, and charcoal combined) is the greatest contributor of non-conventional energy in Panay and Guimaras. This contribution amounts to 1,970,862.82 BFOE (barrels of fuel oil equivalent) which is 99.99% of the total noncon energy utilization. Among the biomass resources, bagasse contributes the most (1,327,659 BFOE, 67%). This is due to the presence of large sugar mills in Iloilo, Capiz and Antique which utilize bagasse as fuel for their boilers. The next highest biomass contribution is by wood/woodwastes (636,736 BFOE, 32%). This is attributable to the use of fuelwood and woodwastes in bakery ovens, in commercial stoves and furnaces, and in pottery and lime kilns. Ricehull contributes only 5,966 BFOE (0.3%) but the amount can be considered important because of the fact that ricehull is always considered as rice milling waste and a problem for rice millers to dispose of.

The other sources of noncon energy, despite the considerable number of installations identified, contribute very insignificant amounts: solar, 126.87 BFOE and wind, 2.46 BFOE. This is because these systems are mostly used for household applications only thereby requiring very small per-unit capacities. Besides, many of the identified installations are inoperational due to a couple of important reasons discussed in the section of Non-operational NES installations.

Noncon Energy Contribution by Technology

By technology (Table 3), boilers are the largest contributors (1,846,175 BFOE). These boilers are used in the sugar centrals to generate steam for power generation and sugar processing and these have very large capacities. Ovens, kilns and furnaces, combined, contribute 119,895.3 BFOE. Most of the ovens are used in bakeries. Kilns and furnaces are used for pottery making and lime production. Biomass fueled dryers also contribute a fair amount (2,694.6 BFOE) while the other remaining technologies have very small BFOE contributions: biogas, 123.3; solar water heater, 113.4; PV, 13.3 and wind pump, 2.5.

NES Installations by Capacity

Table 5 gives a summary of NES installations by capacity. Capacities are expressed in different units for different technologies and the units are by no means equal. This may be a little confusing because larger values do not necessarily mean that the capacities are greater than those with lesser numerical values. Wind pump capacity, for example, is expressed in cubic meters (cu.m.) of water output and the total would result to a larger number compared to those of the other technologies. The boiler capacity, on the other hand is expressed in kilowatt (kW) which will consequently result to a smaller number. In terms of the amount of equivalent energy, however, the boiler capacity would translate to a much bigger amount compared to that of the wind pump because a kilowatt of power could pump hundreds of cubic meters of water.

All the 18 biogas digesters identified have a combined total of 1,325.4 cubic meters of digester capacity. The 8 boilers have a combined capacity of 1,135 kilowatts while the 391 ovens, furnaces and kilns only amounted to 27 kilowatts. The two dryers have a total combined capacity of 2.6 tons per hour while the three gasifiers all found in Iloilo have a total capacity of 71.5 horsepower. The PV systems have a combined capacity of 6,973 watt-peak or only 6.973 kilowatt-peak. The five solar water heaters all found in Aklan registered a total capacity of 925 cubic meters of hot water output. The 288 wind pumps, majority of which are in Iloilo, have a combined capacity of 239,504 cubic meters

AREA	Manure	Bagasse	Rice-hull	Coco-husk	Coco-shell	Wood/ Woodwaste	Char-coal	Total Biomass	Solar	Wind	Total
REGION 6	123	1,327,659	5,967	55	30	636,736	163	1,970,733	127	2	1,970,863
AKLAN	0	0	40	0	17	10,950	0	11,006	115	0	11,121
ANTIQUE	0	26,394	14	55	0	5,193	53	31,708	0	0	31,708
CAPIZ	37	352,919	0	0	0	11,811	18	364,784	2	0	364,786
GUIMARAS	0	0	0	0	0	578,848	0	578,848	0	0	578,848
ILOILO	86	948,347	5,913	0	13	29,934	93	984,387	10	2	984,399

Table 1. NES Contribution by Resource by Province (in BFOE)

AREA	Bio-gas	Boiler	Dryer	Kiln/ Furnace	Other Biomass	Total Biomass	SWH	PV	Total Solar	Wind Pump	Other NES	Total
REGION 6	.23	1,846,175	2,635	119,895	1,872	1,970,700	113.40	13.30	126.70	2.50	33.40	1,970,861
AKLAN	0	0	0	11,007	0	11,007	113.40	1.50	114.90	0.00	0.00	11,121
ANTIQUE	0	3,576	14	28,118	0	31,708	0.00	0.00	0.00	0.00	0.00	31,708
CAPIZ	37	352,919	0	11,829	0	364,784	0.00	2.20	2.20	0.00	0.00	364,787
GUIMARAS	0	548,864	0	29,984	0	578,848	0.00	0.00	0.00	0.40	0.00	578,848
ILOILO	86	940,817	2,621	38,958	1,872	984,354	0.00	9.60	9.60	2.10	33.40	984,400

Table 3. NES Contribution by Technology by Province (in BFOE)

AREA	Biogas (cu.m.)	Boiler (kW)	Dryer (T/hr)	Gasifier (Hp)	Oven/Kiln Furnace (kW)	SWH (cu.m.)	PV (Wp)	Wind Pump (cu.m.)	Wind Turbine (kW)	Other NES (kW)
REGION 6	1,325.4	1,135.0	2.6	71.5	27.0	925.0	6,973.0	239,504.2	1.0	2.0
AKLAN	0.0	0.0	0.0	0.0	0.0	925.0	804.0	0.0	1.0	0.0
ANTIQUE	1.6	60.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CAPIZ	81.0	1,000.0	0.0	0.0	0.0	0.0	1,150.0	0.0	0.0	0.0
GUIMARAS	0.0	0.0	0.0	0.0	10.0	0.0	22.0	27.0	0.0	0.0
ILOILO	1,242.8	75.0	2.1	71.5	17.0	0.0	4,997.0	239,477.2	0.0	2.0

Table 5. NES Installation by Province by Capacity

of pumped water output. The only wind turbine found in Aklan has a capacity of one kilowatt.

Number of NES Installations

A total of 836 NES installations were identified throughout Panay and Guimaras (Table 6). Of these, 552 are found in Iloilo, 97 in Capiz, 86 in Antique, 64 in Aklan and 37 in Guimaras. Ovens, kilns and furnaces, combined, were found to be the most numerous of all NES installations (391). This is followed by wind pumps (288) and PV systems (117). Most of the wind pumps are found in Iloilo and the most common application is domestic water pumping. This proliferation could be attributed to the four wind pump manufacturers all based in Iloilo with Condor having installed the most number of units. PV installations are also numerous in Iloilo and Guimaras because of the implementation of a Rural PV Electrification Project in two pilot barangays in Iloilo and Guimaras by the Special Energy Program of the National Electrification Administration.

Other NES installations identified were biogas systems (18), boilers (8), solar water heaters (5), gasifiers, (3), dryers (2), wind turbine (1), other biomass (2) and other NES (1). These numbers represent what have been identified during the census period and are in no way final. There may still be other existing NES installations which have not yet been identified, new ones are being installed while others are decomissioned or demolished. The database is being updated as new data become available through continuous monitoring and identification of new installations.

Non-operational NES Installations

Various non-operational NES have also been identified during the census and Table 7 gives the summary of these installations by technology and by reasons for being non-operational.

Twenty-two (22) inoperational biogas systems have been identified with ten (10) having technical reasons for being inoperational, one (1) listed economic and eleven (11) gave other reasons. There were four (4) inoperational boilers, two (2) have technical failures, one (1) has economic and one (1) has other reasons. For wind pumps, fifty-nine (59) were identified as inoperational. Forty (40) of these were found to have technical causes of failure, one (1) is economics while eighteen (18) are caused

AREA	Biogas	Boiler	Dryer	Gasifier	Kiln/ Furnace	Other Biomass	SWH	PV	Wind Pump	Wind Turbine	Other NES	Total
REGION 6	18	8	2	3	391	2	5	117	288	1	1	836
AKLAN	0	0	0	0	57	0	5	1	0	1	0	64
ANTIQUE	1	1	1	0	83	0	0	0	0	0	0	86
CAPIZ	9	2	0	0	63	0	0	23	0	0	0	97
GUIMARAS	0	2	0	0	31	0	0	1	3	0	0	37
ILOILO	8	3	1	3	157	2	0	92	285	0	1	552

Table 6. Number of NES Installations by Province

SYSTEMS	REASONS		
	Technical	Economics	Others
BIOMASS	25	12	36
Biogas	10	1	11
Boiler	2	1	1
Dryer	7	3	1
Oven/Kiln/Furnace	3	6	23
Gasifier	3	1	
SOLAR	-	-	-
Solar Water Heater			
Solar Dryer			
Photovoltaic			
WINDPUMP	40	1	18
MICRO-HYDRO	-	-	-
OTHER NES	-	-	-

Table 7. Non-operational NES Installations

by typhoon damage. Of the ovens/kilns/furnace systems, twenty-nine (29) inoperational units have been identified. Only three (3) installations stopped because of technical failure, six (6) because of economic reasons while twenty-three (23) installations listed other reasons for being inoperational. Of the four (4) inoperational gasifiers, three (3) have technical reasons and one (1) has been inoperational due to economic reason.

CONCLUSIONS AND RECOMMENDATIONS

The census revealed in finer details the status of non-conventional energy utilization in the country. NES being site-specific and location-sensitive in application, the details provided by the census could serve as useful inputs for the integration of the use of non-conventional energy systems into the rural development plans in the local, regional and national levels.

These results, however, are not final. There may still be existing systems that the enumerators failed to locate due to lack of information or accessibility constraints. New installations may have come up or existing ones may have been demolished or abandoned. Continuous monitoring and updating is necessary. Nevertheless, these being baseline figures can still serve some meaningful and useful purpose to different users.

The usefulness of these data is not limited to the DOE or the ANECs alone. Other government and non-government institutions as well as private individuals, especially entrepreneurs, could make good use of these data. Thus, there is a need to make these people know of the existence of these data and to make these data easily available to interested users.

REPORT ON RESISTIVITY SURVEY: PANIT-AN, CAPIZ

BERNARDO J. ARELLANO, JR.
Vice-President, ROCHTEST Machinery and Drilling Corporation, San Juan, Metro Manila

Abstract---*Groundwater is found almost everywhere beneath the ground surface. However, poor-well site selection plus improper well design contributes to high investment and operation costs and sometimes lead to the failure of the well. The results of a Geo-resistivity test conducted on each of the proposed well sites in Panit-an, Capiz are presented. Three (3) Vertical Electrical Sounding Points were conducted in the project area with a maximum spread of 350 m. Projected penetration depth was about 200 meters or more. Among the three (3) Vertical Electrical Sounding Points, VES-03 which has the least resistive material was considered, as having the most groundwater potential.*

INTRODUCTION

In every groundwater exploration, a complete assessment of the location, topography, climate, physiology and drainage, and lithology of the project area is important. Likewise, a thorough understanding of the principles governing the occurrence and movement of groundwater, extent, depth and quality of an aquifer present in the area is also necessary.

Location and topography

The project area described in this report is located almost a kilometer away from the Municipality of Panit-an, Roxas. Roxas City bounds the area on the north, the Municipality of Sapian on the north-east, the Municipality of Sigma on the south-east and the Municipality of Pontevedra on the north-west. The topography of the project site can be described as rolling to moderately flat. The average elevation along the midpoint of the project side is around 17 meters above the mean sea level.

Climate

The area, according to Coronas Classification belongs to the type where seasons are not very pronounced, relatively dry from November to April and wet during the rest of the year. Two rainfall stations are located near the projected area. At the northern part is the Culasi rainfall station and at the western side is the Mambusao station. The Mambusao station has a longer period of observation (1950 to 1983) while the Culasi station has only 3 years of record (1971 to 1973). The rainfall data show rainy months start in June and end in November lagging one month behind the Coronas description. The actual record of rainfall for dry and wet seasons are 350.8 mm and 1492.8 mm respctively for Culasi while for Mambusao, the average seasonal rainfall for dry is 946.4 mm and 1651.0 mm for wet. The annual rainfall is 1857.0 mm and 2500.0 for Culasi and Mambusao respectively. It can be seen that rainfall is higher at Mambusao.

Lithology

The oldest rock in the area are the completely folded and faulted sequence of paraschists, chert metaquartzite, marble, phyllites, meta-sediments, meta-volcanics and greywackes. They are exposed in the greater portion of the Busuanga Peninsula.

Igneous rocks of Cretaceous to Oligocene in age particularly the basalt and andesite lava flows, breccia and agglomerate are extensive with the serpentized peridotite, quartz diorite, diorite and gabbro occurring at a lesser extent. The serpentinized rocks are assumed to have intruded through older structures during the late Miocene. Likewise, the intrusions of basalt and andesite are also inferred to have accompanied faulting. The Sara Diorite, the largest intrusive body in the area, is highly weathered and the main body is roughly rectangular in shape. It was formed during the Oligocene period. Thick, swollen intrusive bodies are also found at the Western Cordillera, Guimaras and in the Busuanga Peninsula.

The greywackes which are the oldest dated sedimentary rocks in the island are exposed mostly on the northeastern part of Panay Island. This tertiary rock is intercalated with spillitic basalt.

Overlying uncomformably the basement schists are the sequence of volcanic and sedimentary rocks. During the middle Miocene volcanism intervened with the depositionof the younger Oligocene to middle Miocene sedimentary rocks. This was followed by the continuous accumulations of sediments in this subsiding basin which gave rise to the formation of late Miocene to Pliocene sandstone, shale, limestone and conglomerate. The last formation to be deposited before the upliftment of the area are the Pliocene to Pleistocene claystone, sandstone, siltstone, conglomerate lenses and calcarenite lenses.

Physiology and Drainage

Capiz is one of the four (4) provinces in Panay Island. This island is roughly triangular in shape with its main cordillera running almost north-south starting in the extreme northwest corner of the island, swinging a little to the east then turning to the southwest corner, almost paralleling the western coast. The highest peak elevation is 2,180 meters. The mountains found on the eastern part of the island, forming the south end of the "eastern cordillera" are moderate in height. Their peak elevations range from 400 to 600 meters.

Between the mountain ranges lies the Iloilo Basin with an area of about 40 by 100 kilometers. It is formed by the Panay River, flowing north and the Jalaur River flowing south. A low Divide separates the northern portion of the plain from the southern area.

The streams of the western cordillera are by far the largest and most numerous in the region. From the north to south, the most prominent rivers are the ; Jalaur River, Alibunan River, Tagbacan River, Ulian River, Sirange River, and Tarrao River. These streams are emptying into the protected waters of Iloilo Strait from broad lowlands that extend continuously along the southeast coast.

In the open basin, streams almost everywhere follow meandering courses through broad valleys whose floors are terraced or covered with alluvium that largely conceals bedrock. Inter-stream areas are occupied by hilly tracks or isolated high terrace remnants.

GEO-RESISTIVITY SURVEY

A Geo-resistivity test was conducted on each of the proposed well site to assess its groundwater potential. Three (3) Vertical Electrical Sounding Points were conducted in the project area with a maximum spread of 350.0 meters. Projected penetration depth is about 200 meters or more.

Survey Specification

Instrumentation: OYO Mc-Ohm
Electrode Array: Schlumberger Configuration
Array Lengths: Maximum Power = 200 mA
Potential Spacing (MN)
Maximum Potential Electrode Spacing = 50 m
Electrode Spacing (AB)
Maximum Current Electrode Spacing = 350 m

Methodology

In conducting the resistivity survey, the Schlumberger configuration was adopted. In this method, four electrodes are placed in the ground as shown in Figure 1.

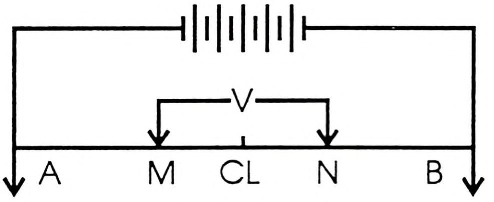

Figure 1. The Schlumberger Configuration

The method involves the application of electric current through the ground across a pair of current electrodes (outer electrodes) and the measurement of potential difference from two potential (inner) electrodes. By increasing the spacing between electrodes progressively, the depth of current penetration is also increased and earth resistance for increasing depths are obtained. Apparent resistivity is obtained by multiplying the earth resistance by a factor "K".

Apparent Resistivity = K x R

where:

$$K = \pi \frac{(AB - MN)(AB + MN)}{4MN}$$

$$R = \frac{V}{I} \quad (Ohms)$$

Groundwater Recharge

Groundwater recharge into the aquifers is rainfall percolating into the catchment areas of Panay: Aklan, Mambusao and Maayon Rivers and smaller drainage systems within the two Provinces. The aquifers found in the area are only for limited, small scale development in view of unfavorable low permeability of the aquifers, relatively fast surface run-off due to the almost denuded forest cover of the region and moderate to steep slopes.

Annual groundwater recharge range from less than 0.01 m to over 0.20 m per year. On the other hand, annual replenishable storage in the sand and gravel deposits is estimated at less than 0.50 meter to over 1.0 meter per year.

ANALYSIS AND DISCUSSION OF RESULTS

Surface geologic mapping within and around the property show that the project area is underlain by a volcanic rock, namely basalt grading to andesitic basalt. These rocks are massive and frequently fractured/jointed. Overburden in the area is relatively thin, less than 2.00 meter thick.

The results of resistivity investigation are shown in Table 1. Three (3) different materials were detected underlying the Project Area. They are the overburden, weathered rock formation and a fresh rock formation namely the volcanic flow. The overburden material has a resistivity value of 14.90 ohm-meter in VES-01, 19.70 ohm-meter in VES-02 and 34.40 ohm-meter in VES-03 (Table 1). Thickness range from 1.80 meters in VES-01, 1.50 meters in VES-02 and 0.30 meters in VES-03. The next layer, weathered material, has a resistivity value that range from 9.90 ohm-meter to as high as 37.10 ohm-meter in VES-01. Their thickness range from 1.90 meters in VES-03 to 6.30 meters in VES-02. The third layer which is the volcanic flow composed of basalt grading to andesitic basalt has a resistivity value of 156.10 ohm-meter in VES-01, 192.80 ohm-meter in VES-02 and 122.50-129.30 ohm-meter in VES-03. The thickness of the third layer in VES-01 is 430.30 meters, in VES-02 311.60 meters and in VES-03 196.80 meters.

Although all three (3) Vertical Electrical Sounding Points contain the volcanic flow material, only VES-03, which has the least resistive material can be considered as having the most groundwater potential in the surveyed area. The other two VES Points, 1 and 2, which are also underlain by the same material have much higher resistivity values, in the order of 156.10 (VES-01) to 192.80 ohm-meter (VES-02).

The availability of groundwater in a volcanic rock depends on their secondary porosity, fracture/joint system that they contain. The big difference in the resistivity value (VES-01 and VES-02 to VES-03) might be due to the above mentioned phenomena. The highly resistive material in VES-02 has lesser fracturing thus offers lesser groundwater than the other VES Points, 1 and 2. VES-01 which has a moderately resistive volcanic flow material has also been considered as an aquifer but due to its moderate resistivity value, groundwater availability in this well is limited. Thus among the three (3) VES Points only VES-03 which has a much lesser resistivity value in the order of 122.50 ohm-meter to 129.30 ohm-meter, is believed to have the greatest potential in terms of groundwater availability. In terms of groundwater recharge, it

VES POINTS	RESISTIVITY LAYER (M)	(OHM-M)	THICK (METER)	DEPTH (METER)	INFERRED GEOLOGY	GROUNDWATER CONDITION
VES-01	1st	14.90	1.80	1.80	Overburden	No groundwater available
	2nd	37.10	2.40	4.20	Weathered materials	No groundwater available
	3rd	9.90	1.80	6.00	Weathered materials	No groundwater available
	4th	156.10	430.30	436.30	Volcanic flow	Aquifer
	5th	69.30				
VES-02	1st	19.70	1.50	1.50	Overburden	No groundwater available
	2nd	20.10	6.30	7.80	Weathered materials	No groundwater available
	3rd	192.80	311.60	319.40	Volcanic flow	Aquiclude
	4th	59.60				
VES-03	1st	34.40	0.30	0.30	Overburden	No groundwater available
	2nd	10.80	1.90	2.20	Weathered materials	No groundwater available
	3rd	129.30	70.30	72.50	Volcanic flow	Aquifer
	4th	122.50	126.50	199.00	Volcanic flow	Aquifer
	5th	380.00				

PROJECT: Oyster Processing Plant LOCATION: Panit-an, Capiz

Table 1. Tabulated Result of Geo-Electric Survey

has also the advantage over the other two VES Points since it is located in a lagoon-like depression.

Design of the well

A preliminary well design was prepared based on the result of the resistivity survey (Fig. 2). The design or diameter of the well can accomodate a pump with a discharge capacity of 60 to 115 gallons per minute (gpm) which is the anticipated yield and an assumed total dynamic head of 50 meters.

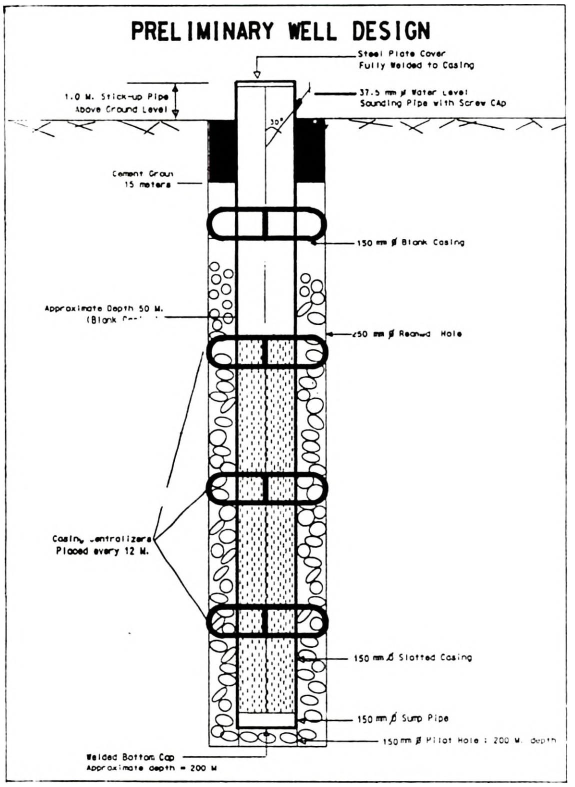

Figure 1. Preliminary Well Design

Increasing the diameter of the well will give a minimal increase in yield as this is controlled by the type of aquifer and recharge. Final lengths of casings, blank and screen will depend on the result of well logs. An experienced Hydrogeologist should interpret the geologic and electric logs of the well where the final design will be based. Pea gravel placed 2 inches on both sides of screen will filter out small particles that may enter the well. Final design of pump will depend on the result of the pumping test conducted on the well.

CONCLUSIONS/RECOMMENDATIONS

After evaluating and correlating the gathered field data on the local geology and other existing records of nearby wells the following were recommended:

1. The site for exploratory drilling should be in VES-03.
2. If the yield in VES-03 is not sufficient to meet the water supply demand. additional well maybe drilled on VES-01.
3. The well will have the configuration described in Figure 1.
4. Final length and depth of screens will depend on the result of geologic and electric logs performed by an experienced Hydrogeologist.
5. For proper construction of well, grouting should be done after the pumping test, to alloe the settlement and compaction of the pea gravel. Additional 5 meters of gravel pack from the uppermost part of the screen/perforation is reserved for future development of wells.

PROFILE OF CENTRAL PHILIPPINE UNIVERSITY

Central Philippine University is a non-stock, non-profit Christian institution where a well rounded program of education is offered under influences that strengthen faith, build up character and promote scholarship and research. Its motto is "Scientia et Fides" or Science and Faith.

Central Philippine University was founded by American Baptist missionaries as the Jaro Industrial School in 1905. It started as an elementary school where students work for their tuition and board. Growing steadily, it became a college in 1923 and a university in 1953.

Located on a beautiful twenty-four hectare campus, CPU has an atmosphere conducive to study and reflection. There are more than thirty buildings used for classrooms, offices, dormitories and other support facilities.

CPU offers courses and undertakes researches that support national objectives and answer regional and national needs. Research institutes were established to strengthen the research capabilities of the University. These include the Social Science Research Institute (SSRI), the Western Visayas Small Business Institute (WVSBI) and the Businessman's Information Center (BIC). WVSBI and BIC were established in cooperation with the Department of Trade and Industry. CPU is also a member of the Western Visayas Agriculture and Resources Research Development Consortium (WESVARRDEC). The CPU-Affiliated Non-Conventional Energy Center was established in 1989 to serve as the extension arm of the Department of Energy in Western Visayas.

CPU is a member of several national and international organizations among which are the Association of Christian Schools and Colleges (ACSC) and the Association of Christian Universities and Colleges in Asia (ACUCA).

CPU COLLEGE OF ENGINEERING

The CPU College of Engineering offers complete 5-year programs for the following disciplines: Chemical Engineering, Civil Engineering, Electronics and Communications Engineering, Electrical Engineering, Mechanical Engineering, and Master of Engineering.

In 1977, the college was chosen as one of the ten resource-base schools of engineering in the country by the Educational Development Projects Implementing Task Force (EDPITAF). The succeeding years saw the establishment of the Center for Civil Engineering Education (CCEE) in 1985 and the CPU-Affiliated Non-Conventional Energy Center(CPU-ANEC) in 1989. CCEE is an equipment fabrication project which received a grant from the United Board for Christian Higher Education in Asia while the CPU-ANEC which is being managed by the College is a joint project of CPU and the Department of Energy. In 1995, the College was cited by the Department of Science and Technology as the Engineering and Science Education Project (ESEP) School for Panay.

The College of Engineering dreams of reaching out to more students and providing them quality education with a distinct brand of academic excellence founded on scientific and Christian principles.

As the College celebrates its sixtieth anniversary this year, the maiden issue of the Engineering Journal is published to inspire both the faculty and the students to take a bolder step towards the world of research. It is hoped that the publication of the Engineering Journal would pave a way to more extensive engineering research work in the years ahead.

ENGINEERING JOURNAL
The Official Journal of the College of Engineering, Central Philippine University
Vol. I, No. 1, July 1996

Contents

Cirilo C. Calibjo	1	Tuning of Speed-Governing System for Kalayaan Pumped Storage Power Plant
Walden S. Rio	7	Development of a Low-Cost Tension-Compression Equipment
Smileta Grace C. Cuales	11	Solid Waste Management System in Iloilo City
Dahlia H. Pescos	21	Water Quality Testing and Treatment in the Proposed CPU Water Laboratory
Naomi P. Carnaje	27	Monitoring the Performance of Anaerobic Digesters at High Loading Rates for Failure Control and Optimization
Jeriel G. Militar	37	The Non-conventional Energy Systems (NES) Census of Panay and Guimaras
Bernardo J. Arellano, Jr.	43	Report on Resistivity Survey: Panit-an, Capiz