Medical waste treatment and electricity generation using pyrolyzer-rankine cycle for specialty hospitals in Quezon City, Philippines

F Manegdeg*, L O Coronado and R Paña

Department of Mechanical Engineering, College of Engineering, University of the Philippines Diliman, Quezon City 1101, Philippines

*E-mail: fgmanegdeg@yahoo.com

Abstract. Acquisition, treatment, and final disposal of health-care waste is a vital public concern. Improper disposal has heightened this concern as it could lead to a widened risk of transmission of agents associated with blood-borne diseases. One of the ways to address these concerns is waste disposal and waste-to-energy plant. This facility is envisioned not only to manage hazardous wastes from hospitals with the least emissions of toxic substances and greenhouse gases but also to generate electricity. This study investigated the feasibility of developing waste disposal and waste-to-energy plant which involved: the selection of hospital type and location, waste composition, energy conversion, and power plant technology, and financial viability of the plant. The sampling design process identified the hospitals to be surveyed. The criteria include proximity of the hospitals, number of beds, and type of hospitals. A survey of waste generation across the specialty hospitals was then conducted and determined the type of waste, the quantity of the wastes produced, the percentage by weight, bulk density, and composition of the wastes. A selection was done to determine the energy conversion technology. The electric power plant technology was then selected knowing the characterization of the synthetic gas. The average waste generation was found to be 579 kg waste per day which has 29.062 kJ/kg calorific value. The study shows that electricity could be generated from this waste by utilizing a Pyrolyzer - Rankine Cycle power plant and is viable with a payback period of 5 years, and a Benefit-to-Cost ratio of 4. A business plan and enabling environment for the establishment of the Pyrolyzer – Rankine Cycle power plant is recommended to be studied.

Keywords: Waste-to-energy, Medical waste, Pyrolyzer, Rankine cycle, WACS

1. Introduction

Globally, the acquisition, treatment, and final disposal of health-care waste is a vital public concern. Over the past few years, this issue has increased significantly because of improper disposal. The World Health Organization [1] cites that the individuals at risk from exposure to hazardous health care waste include: health care personnel; patients and visitors in health-care facilities or even in home care; health care establishments or hospital affiliated workers such as laundry, transportation, and waste handling; and workers in waste disposal establishments, including scavengers. Improper disposal could lead to widened risk not only to the individuals but to the general public as well [2].

Contact to these hazardous health-care wastes is associated with a potential risk of infection and transmission of various viruses like hepatitis B, and human immunodeficiency, and other agents inherent
with blood borne diseases. Besides, several countries had negative reactions on treating health care waste through incineration due to its associated emissions that may carry elevated amount of toxic compounds and dangerous microorganisms that is capable of surviving under this conditions [3]. These concerns prompted governments to pass legislation to address the lack of understanding of the grave risk associated with these wastes and regulate the collection, treatment, and disposal of health-care wastes.

There have been a few studies that investigated the feasibility of converting waste into energy in the Philippines [1,3]. Researchers have studied the waste characterization, waste-to-energy sizing, and viability of a waste-to-energy plant. However, there has not been a study on the feasibility of waste disposal and waste-to-energy plant that does not only investigates the waste characterization and viability but also the selection of an energy conversion technology. This technology must keenly consider not only the waste influent and effluent but also to its emissions (i.e., toxic compounds), which are of equal importance [4].

The objective of the study is to (a) select the hospitals for the survey, (b) determine the characterization of the waste generated by the hospitals (c) select the suitable conversion technology utilizing the medical waste, (d) determine the appropriate power plant technology for electricity generation, and (e) calculate the financial feasibility of building a waste disposal and waste-to-energy plant.

2. Methodology

2.1. Sampling Design
Quezon City was selected as the location of the waste disposal and waste-to-energy plant based on the screening criteria that include crime rate, environmental safety, ease of obtaining business, real expenditure per capita, peace and order, population growth, land area, and government incentives.

![Figure 1. Sampling Design process flow.](image)

The specialty hospitals in Quezon City were selected based on bed capacity, type of hospital, proximity to each other, and business land area.

2.2. Waste Analysis and Characterization Study
The hospitals sampled are the Philippine Heart Center (PHC), National Kidney and Transplant Institute (NKTI), Lung Center of the Philippines (LCP), and the Philippine Children’s Medical Center (PCMC). The specialty hospitals have capacities of 352, 247, 210, and 200, respectively. The waste generation survey across the four specialty hospitals in Quezon City was conducted for 37 days.
The quantity of the waste produced and the percentage by weight of infectious waste to the total generated waste were obtained during the survey. Solid wastes are collected from four different sources of each of the hospitals, namely: Out-patient Department (OPD); Emergency Room (ER); General Wards (WARD); and Intensive Care Unit (PICU). The sampling was conducted over five days. The wastes were classified and identified into two major classifications: a) infectious, and b) non-infectious. The infectious wastes were gathered and transferred to the treatment and processing sector, where the wastes were weighed. Bulk density of the wastes are identified using this weights. The non-infectious wastes were transferred to the waste segregation and disposal section where the wastes were analysed and characterized according to the procedures of ASTM D5231 standard test method for identifying the unprocessed municipal solid waste composition. The wastes were also weighed and sorted into following characterization: garden/yard waste, food waste, paper/cardboard waste, rubber/leather waste, glass waste, metal waste, wood waste, plastic waste, diapers, textiles, and special waste like batteries.

The four hospitals are estimated to supply an average of 579 kg of infectious waste per day. The average calorific value of infectious waste is computed to be 29,062 kJ/kg.

| Source of waste | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Total (kg) | Average (kg/day) |
|-----------------|-------|-------|-------|-------|-------|------------|-----------------|
| Total Weight    | 534   | 728   | 569   | 509   | 556   | 2,896      | 579             |
| Infectious      |       |       |       |       |       |            |                 |
| PICU            | 68    | 67    | 44    | 77    | 35    | 291        | 58              |
| Ward            | 237   | 200   | 180   | 71    | 77    | 765        | 153             |
| OPD             | 7     | 25    | 52    | 41    | 81    | 206        | 41              |
| ER-Surgery      | 94    | 85    | 77    | 65    | 70    | 391        | 78              |
| Total Weight    | 400   | 333   | 320   | 279   | 409   | 1,742      | 348             |
| Grand Total     | 934   | 1,061 | 889   | 788   | 965   | 4,638      | 928             |
| No. of beds     | 252   | 252   | 252   | 252   | 252   | 252        |                 |
| Waste Generation (kg/bed) | | | | | | | |
| Infectious      | 2.1   | 2.8   | 2.2   | 2.0   | 2.2   | 2.3        |                 |
| Totals          | 3.7   | 4.2   | 3.5   | 3.1   | 3.8   | 3.6        |                 |

| Component        | PICU (%) | Ward (%) | OPD (%) | ER-Surgery (%) | Totals |
|------------------|----------|----------|---------|----------------|--------|
| Garden/Yard Wastes | 0.1       | 0.0      | 0.0     | 0.0            | 0.0    |
| Food/Vegetables   | 29.9      | 30.8     | 26.4    | 28.7           | 29.0   |
| Paper/Cardboard   | 14.1      | 16.6     | 10.7    | 17.4           | 14.7   |
| Rubber/Leather    | 0.9       | 0.8      | 4.4     | 7.0            | 3.3    |
| Glass             | 2.6       | 2.4      | 2.9     | 3.3            | 2.9    |
| Metals/Cans       | 1.0       | 1.9      | 1.3     | 2.0            | 1.6    |
| Wood              | 2.3       | 0.2      | 2.4     | 1.1            | 1.6    |
| Plastics          | 29.9      | 24.1     | 13.9    | 27.4           | 23.9   |
| Diapers           | 9.2       | 16.4     | 7.7     | 0.0            | 8.4    |
| Textiles          | 4.5       | 4.7      | 15.0    | 10.2           | 8.6    |

2.3 Selection Processes

A conversion technology will be used to convert the medical waste into gas or liquid fuel. The initial alternatives such as incineration, biodigestion, gasification, and liquefaction were screened out as they are not compliant with the Clean Air Act [5-9]. The pyrolyzer was chosen over microwave and plasma technologies as the best conversion technology based on net efficiency, capital expenditure, operation and maintenance cost, CO₂ emission, service life span, process temperature, capacity range, dioxins and furans emission, net energy generation potential, plant capacity, and electricity input.
Figure 2. Selection of energy conversion technology for medical waste.

Figure 3. Selection of power plant for electricity generation.

For the power plant, three alternatives were considered. They were the internal combustion engine, Gas turbine, and Rankine Cycle. Using the selection criteria such as efficiency, maximum cycle temperature, capital expenditure, noise level, CO₂ emission, land area needed, and source power limit [10-14], the Rankine Cycle was selected as the best power plant to be installed.

3. Results and Discussion

3.1 Demand and Supply

The energy demand and peak load of the hospital are determined by process analysis. The power plant is not only required to reach the daily demand but also to be capable of supplying the peak load. This would be the basis for the energy supply from the Pyrolyzer-Rankine plant.

The sector of the LCP (Lung Center of the Philippines) where the electricity will be supplied is the Emergency and Outpatient Department. It was selected based on the number of patients served, expenses, priority, number of employees, number of significant medical equipment [15]. The demand for this sector can be sufficiently supplied by the power plant. Using the data from process analysis and actual energy demand of the hospital, energy demand can be determined. Linear regression was used to identify the demand after twenty years and future peak load (Table 4).

Table 3. Actual Supplied Load to LCP (MW).

| Year         | 2013 | 2015 | 2016 | 2017 | 2018 |
|--------------|------|------|------|------|------|
| First quarter| 2,890| 2,750| 3,150| 3,070| 2,990|
| Second quarter| 2,530| 3,020| 3,279| 3,373| 2,970|
| Third quarter | 2,940| 2,678| 2,956| 3,111| 2,876|
| Fourth quarter| 2,749| 2,971| 3,027| 3,150| 3,268|
| Annual load   | 11,109| 11,419| 12,412| 12,704| 12,104|
Table 4. Forecast of Load Supply.

| LCP total annual load after 20 years (All 26 sectors) in MW | Load for Emergency medicine department after 20 years |
|------------------------------------------------------------|-----------------------------------------------------|
| Annual load (MW)                                            | Daily Load (MW)                                     |
| Hourly load (kW)                                            |                                                     |
| 18,113.6                                                   | 696.7                                              |
| 79.5                                                       |                                                     |

From the waste generation survey, the four hospitals are estimated to supply an average of 579 kg waste/day.

3.2 Waste-to-Energy Conversion

Using a Pyrolyzer conversion technology at 800°C reaction temperature, the end products will be composed of 94.1% synthetic gas and 5.9% bio-char and bio-oil [16,17]. The synthetic gas is composed of 48.2% H₂, 22.6% CO, 15.2% CO₂, and 8.1% CH₄, while on per element basis is 15.3% C, 21.47% H, 17.67% O, and 0% N. Using Equation (1), the higher heating value (HHV) of the synthetic gas was computed to be HHV for the syngas at 32,839.36 kJ/kg. With a 94.1% percent syngas in the product, the syngas mass flow rate \( m_f \) is 68.1 kg/hr.

\[
HHV = 354.68C + 1376.29H - 15.92 Ash - 124.69(O + N) + 71.26
\]

Using the computed syngas HHV and mass flow rate, pyrolyzer input work of 57.5 kW, and power plant operating parameters assumptions, the system efficiency is computed using Equation (2).

\[
\text{Efficiency} = \frac{\text{Total (net) work output}}{\text{input waste mass flow rate} \times \text{Input waste calorific value}}
\]

The Rankine Cycle power plant efficiency was computed to be 35.5% while the system (Pyrolyzer-Rankine Cycle) efficiency was 17.8%.

3.3 Financial Feasibility

The total Capital cost for the waste disposal and waste-to-energy plant is PhP 40,000,000 (US$ 800,000) where PhP 12,500,000 (US$ 248,000) will be financed through a loan, with the remaining through equity. The revenue streams of the plant include income from waste disposal, electricity generation, and sale of carbon credit. The annual revenue is estimated to be PhP 24,700,000 (US$ 490,000).

With a discount rate of 8.4%, the Net Present Value (NPV) of the plant’s net cash flow in 20 years of operation is PhP 198,290,000 (US$ 3,930,000). The Benefit-to-Cost ratio is found to be 4 and the payback period is 5 years. Throughout 20 years of operation, the Return on Investment (ROI) is calculated to be 297%. This does not include the social cost that will be avoided by the Quezon City government.

4. Conclusions

The study shows that the waste disposal and waste-to-energy plant in Quezon City that treats medical waste via Pyrolyzer-Rankine Cycle power plant are found to be feasible promising an ROI of 297% throughout its operating years and a payback period of 5 years. Moreover, aside from revenue from the electricity generated, the public will be spared from the risks associated with improper disposal of infectious medical waste.

5. Recommendations

Following the feasibility of building waste disposal and waste-to-energy plant in Quezon City, it is recommended that a business plan is developed and an enabling environment for the establishment and operation of the waste disposal and waste-to-energy plant be formulated.
Acknowledgment
The authors would like to extend their gratitude to the staff of the National Kidney and Transplant Institute, Lung Center of the Philippines, Philippine Heart Center, and Philippine Children’s Medical Center for providing the waste generation data. Appreciation is also extended to the staff of Quezon City Environmental Protection and Waste Management Department for providing waste generation data, as well as to the Hazardous Waste Management Department of the Department of Environment and Natural Resources (DENR) for responding to our data request, and to the University of the Philippines Office of International Linkages and the College of Engineering for providing financial support.

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