ANALYSIS AND DEVELOPMENT OF HIGH RATE COMPOSTING SYSTEM USING MUNICIPAL SOLID WASTE IN SRI LANKA

By

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Research work supervised

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Abstract

Municipal solid waste has become a major problem in every country in terms of public health and environmental damage. As a developing country, Sri Lanka too faces the same challenge not only by public health and environmental damage, but also in finding an affordable yet effective technology, which is socially and economically acceptable. Municipal Solid Waste (MSW) is qualitatively heterogeneous. Therefore, it is difficult to find a unique solution for proper treatment. I.e. The solution is always an integrated one, which consists of sorting, biological/thermal/chemical treatment, recycling and land filling. However quantification and characterization of solid waste in a given area are important factors prior to selecting suitable technology. Therefore, it is required to find waste quantity, composition, density, moisture content, annual rate of waste generation and calorific value of waste etc in a given area. In Sri Lanka, moisture content and organic fraction are reasonably high and lack of high thermal value materials in solid waste stream, have lead to an overall low calorific value of MSW. The general practice for handling the MSW is low rate composting systems. Most have been failed due to poor process management, lack of knowledge of proper operation (feedstock formulation, process control, end point indicators), poor product quality, long lead-time, weaker community participation and lack of public awareness. In all systems existing at present bad odor and leachate are unsolved issues. These systems have largely been controlled by default rather than by design. Thus, losing the public confidence on composting is inevitable.

Properly engineered composting systems require to monitor and control of key parameters such as aeration, C/N ratio of feedstock, pile temperature, moisture content and particle size. The broad objectives of the research were, a detailed review of solid waste management practices in Sri Lanka and process of composting, Identification of composting strategies & evaluation of systems, and design of a high rate in-vessel composting system. During the design, it was considered to maintain the optimum environmental conditions for higher rate of decomposition by microbial activities, aeration demands, and required moisture content throughout the process. The main component of the model is a rotating drum reactor, which is operated under the thermophilic temperature conditions. The rate of decomposition at thermophilic temperatures is much higher (low residence time) than the mesophilic temperatures. A shredder could be used for size reduction of incoming feed in order to determine the optimum particle size. As source separation is very poor in Sri Lanka, this research addresses the possibility of using a semi-mechanized waste segregation device at the secondary stage. Special care was taken to control the odor and leachate of the system. On the other hand, the confidence on low rate windrow / static pile composting among the people have been lost due to the process mismanagement. Therefore, the design offers to have an energy optimized semi mechanized system in which minimum labor contact with the waste occurs.

The reactor is operated by a feedback control system, in which real-time monitoring of critical parameters are done. Based on the existing value and the set point (optimum value for each parameter: moisture and aeration), the control action is taken. Further, intermittent rotation of the reactor facilitates the proper temperature distribution inside, particle size reduction and uniform porosity throughout the mixture while reducing the energy consumption faced by the continuous operated system. Sensor

setup at different heights of the reactor monitors the temperature and moisture content along the axis of the system. It has been observed that moisture is the limiting factor, when the temperature feedback control system is used in the composting. However, real-time monitoring of the moisture content avoids this difficulty. Further, weak pathogen inactivation is a major drawback found in most of the manually turned systems. Intermittent rotation and temperature feedback control system ensure the proper temperature distribution across the reactor and mixes the matrix properly in order to subject to uniform temperature throughout the mass. The modular basis helps for easy movement and it consumes less space compared to the windrow system. According to the national database on solid waste in Sri Lanka, 88% of Local Authorities collects less than 10 Tons per day. This shows the possibility of use of modular units in areas, where space is limited. Close monitoring of the critical parameters of the system helps to maintain optimal decomposition rates while ensuring consisted product quality during the decomposition.

Since organic farming is a growing area in export-oriented agriculture (Tea, vegetables) in our country, this research helps to produce a good soil conditioner (with consistent finished product) using MSW while solving a major environmental problem. Tea plantation companies put special attention to identify the requirements of quality standards for the production of famous 'Ceylon Tea'. Hence as a part of this work, analysis of the critical parameters of the compost, manufactured by different organizations in the country that use solid waste as the substrate was carried out. It is important to match composting quality and the particular plantation requirement to develop a sustainable market for the compost produced using MSW. This has been particularly lacking in the Sri Lankan market with the compost producer hoping to realize a good price for anything that is produced; an expectation that had not been realized.

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The author wishes to express his sincere gratitude to Dr. Ajith De Alwis, Dr. Sumith Pilapitiya, Prof. Malik Ranasinghe, Dr. Mrs. Indrika Abeygunawardhana and Mr. S. Pathinathar for their valuable advices, guidance, encouragement and the extended support through out the research. It was really a privilege to work under them and their kind directions, which helped me to understand the art of researches. The whole research was beyond the imagination, unless otherwise the necessary funding arrangements were done by Dr. Ajith de Alwis, Dr. Sumith Pilapitiya and Prof. Malik Ranasinghe.

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This thesis is dedicated to my parents for caring & making me to see the world as a better place and to Dr. Ajith de Alwis and Dr. Sumith Pilapitiya who paved the way for graduate studies and insight into the research making the life more meaningful.

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Declaration

This thesis is a report of research work carried out in the Department of Civil Engineering, University of Moratuwa, Sri Lanka, between December 2000 and February 2002. The work included in the thesis in part or whole has not been submitted for any other academic qualification at any institution.

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Chapter One

Introduction

Municipal Solid Waste (MSW) has become a major problem for every country in the turn of last century. The issue has become a problem to Sri Lanka too. As population continues to grow, with changing life styles of people, rapid urbanization and lack of lands within close proximity to urban areas have led the problem to be addressed more complicated.

1.1 Garbage – Urban waste management issue

The waste stream is heterogeneous and quantity of collection varies from less than one (1) ton per day (TPD) to more than six hundred and fifty (650) tons per day depending on the area in Sri Lanka. The solid waste consists of kitchen waste, garden waste, clinical and infectious waste, commercial and industrial waste without any separation. Still, the waste separation at source is new to Sri Lanka, though some pilot projects have shown promising results. The mixed waste increases the cost of processing and consumes more time and resources. Further, it endangers the people who handle this mixed waste and in the long term poses a serious environmental threaten. This has led much difficulty in treating the solid waste in an appropriate manner. Usually, Local Authorities (LAs) are responsible for collecting and proper disposal of waste generated by the people within its territory. The service today is far from satisfactory. Not only inadequate resources have hindered their work to an acceptable level, but also, they have not received the public cooperation as required i.e. civic responsibility. Hence, open dumps and poor collection are commonly evident throughout the country. On the other hand, environmentally sensitive areas like wetlands; beaches have been used as common waste disposal sites (de Alwis, 2000). Figures 1.1 and 1.2 show two examples from current practices.

Fig 1.1: Garbage as beach fronts

Fig 1.2: Mixed waste (medical waste with city waste)

When examples of poor practices are examined and visuals from daily practices are shown in media, it appears to be that most of LAs neither have a clear-cut vision for successful waste management nor consider it as a priority area. This has led many problems in implementing the waste management systems in Sri Lanka (Manipura and Jayawardhana, 2000). However, it is important to introduce and improve the concept of source separation for successful implementation of any integrated solid waste management solution. In order to provide a balance waste management service, it is required to consider all elements associated with it. Activities related to service production (technology, men and material), level of service, cost related to each activity, the cost recovery concept and stakeholders participation decide the sustainability of any solid waste management system in a given area (Ebertz et al., 2000). The concept of polluter pays should be encouraged and "NIMBY" (Not In My Back Yard) syndrome has to be cured promptly. In order to achieve these, it is much required to increase the public awareness, public private partnerships as well as active contribution of stakeholders in the solid waste management of Sri Lanka.

1.2 Problems of mismanagement of solid waste

Mismanagement of solid waste has risen many problems such as use of wetlands as disposal sites, ground water contamination, air pollution, decrease of property value, loss of amenity, soil erosion in sloped in hilly areas and so on.

As a result of use of wetlands as waste disposal sites, the flood retention capacity have been drastically reduced in some of the more densely populated urban areas. This lower capacity of flood retention leads to have temporary flood conditions even by a small rain in places like Colombo, some part of Ratmalana, Dehiwala, Mount Lavinia and Kotte. On the other hand, there are many consequences due to this temporary flood situation such as Diarrhea, mosquitoes / mosquito breeding places contributing to many mosquito related diseases, damage to properties, drainage lines and highways and even traffic management problems during the floods etc. Recent dengue outbreaks lead much agitated campaigns against solid waste dumping, though as the problem subsides due to seasonal changes the interest in causes also subsides.

Air pollution due to open dumping is easier to understand, as some effects are all too evident. Methane (CH_4) is released to air by the anaerobic digestion of waste. And, CH_4 is a Green House Gas (GHG) about twenty one times GWP (global warming potential) that of CO_2. On the other hand, H_2S, organic mercaptants are responsible for the bad odour due to anaerobic digestion of solid waste. Open burning of waste is also a common practice, which emits environmentally harmful gasses and soot to the environment.

Ground water contamination is another major problem due to haphazard solid waste disposal. Severity of the problem is much higher in the western province in Sri Lanka as pointed by the UNEP 2001. Further UNEP 2001 quoted from National Water Supply & Drainage Board (NWSDB), the NWSDB had considered the option of using groundwater to increase the supply of potable water to residents in the Greater Colombo area. However, due to the pollution of the ground water aquifers in the region, primarily caused by open dumping, the NWSDB was not able to proceed with this option. With Japanese funding amounting to Rs. 8.3 billion, the NWSDB has now initiated a project to tap the Kalu Ganga as a source for the Greater Colombo Area. This is just only one case. On the other hand, it is difficult to understand the reasoning of the people who protest against the sanitary landfills by considering the possible leachate percolation and do not see the ground water contamination due to ad-hoc dumping carried out all over the country. Soil erosion is aggravated, when dumping garbage on the slopes. Especially, in the central part of the island, most of the LAs use to dump the garbage along the roads leading slopes then to water streams (fig. 1.3). Poultry waste have been dumped along the main salten as shown fig 1.4.

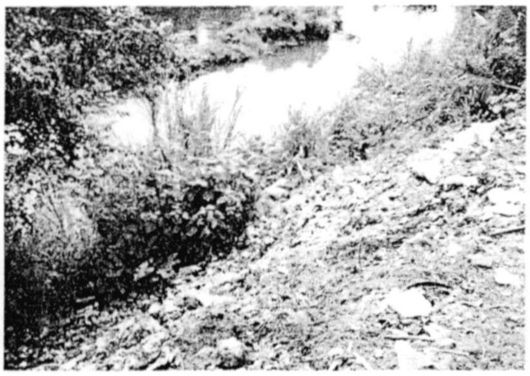


Fig 1.3: Waste disposal along banks of streams.

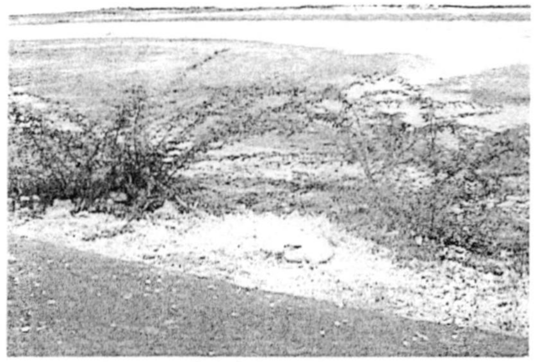


Fig 1.4: Poultry waste dumped near saltens

Decrease of property values is another negative economic result of bad disposal practices. Bad odour and the loss of amenities are caused, when haphazard garbage dumps are located. Today the "flower of valley" (Bloemandhal as named by the Dutch) became a mountain of garbage in the heart of the city of Colombo where in which presently the city garbage is dumped.

Attidiya and Muthurajawela are used to dump garbage from Dehiwala – Mount Lavinia and Colombo municipalities respectively. However, these areas are protected conservative areas. It is understood that the biodiversity of these areas are affected by the bad disposal of solid waste. This would lead to extinction of some species living in those environments. However, these laws are openly flouted by the government agencies themselves.

In addition to these direct consequences, the tourism industry will also suffer. The present haphazard disposal practices of solid waste create a negative image of the country in a visitor as of all wastes perhaps the solid waste is the least mobile and the most visible!

1.3 The need analysis for Integrated Solid Waste Management (ISWM)

In an integrated waste management system, it addresses all the components of the waste stream suitably. Since, there is no single solution for the whole waste stream. ISWM consists of waste reduction, reuse, recycle and final disposal in a given area with active participation of stakeholders.

Reduction of the waste generation is the first priority in the waste management hierarchy. In order to achieve this, it is required to have good public awareness as well as proper understanding of those who produce waste. Government should introduce the suitable legal framework to encourage the people to reduce the garbage produced by them. For example collection fee for the waste produced by the public. However, legal framework should not exceed the practical condition in which the implementation is difficult. Ex. banning of polythene use; food & packaging industry heavily depend on this material. Manufacturers can encourage their consumers to return the used packs / bottles and giving some discount on that. By increasing the thickness of grocery bags ("Sili Sili bag) and, hence putting higher price for those bags, people should be encouraged to reuse them (Personnel communication, De Alwis and Pilapitiya).

Second priority of waste management after reduce, is the encouragement of people to reuse material as much as possible. This reduces the use of natural resources, energy and environmental damage. Material, which neither reuses nor recycles, has to be sent to the final disposal. For example, excessive quantities of building debris can be sent to a controlled/engineered landfill. It should be encouraged that the minimum quantity of organic waste to be sent to the final disposal, which prevents the cost of lining material and the possibility of ground water contamination.

MSW stream consists of heterogeneous materials, which prevents having a unique solution for the proper treatment. Therefore, the treatment procedure is constituent specific. Table 1 indicates the solid waste composition in the Colombo city (ERM, 1999).

Table 1: Typical waste composition in Sri Lanka

No.	Constituent	Percentage / (%)
01	Organic Matter	84.26
02	Plastic / Polythene	6.61
03	Metal	5.42
04	Paper	1.26
05	Glass	0.29
06	Other	1.49

Source: REM, 1999

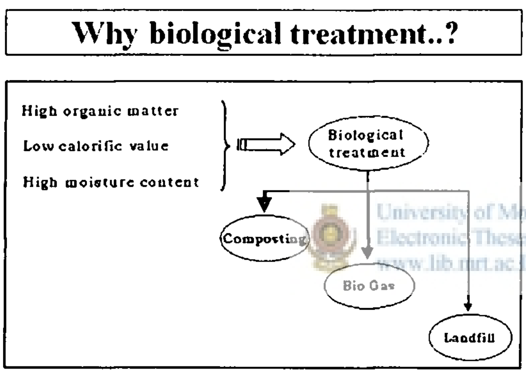
When analyzing the solid waste stream in our country, it is clear that the dominant constituent is organic in nature (Table 01). Thus the main pollutant is the organic fraction. This organic fraction comprises of household organic waste, market waste, slaughterhouse waste, sewage sludge, paper, cardboard and some commercial organic waste. De Alwis (1995) and Moratuwa study of Pathinathar (1985) have shown the high moisture content of the solid waste stream. Recycling of organic fraction can help to eliminate the major environmental problems posed by them. It is the putrescible fraction, which leads to bad odor and leachate with loss of amenity. Organic waste recycling ends with a useful product, which can be used in land reclamation. For this, composting ând biogas could be made use effectively in our country.

Therefore, biological treatment has a greater role to play in Sri Lankan solid waste management. However, due to the attitudinal problems, substrates like sewage sludge cannot be used in composting in the present context. However, the successful use of human excreta in Chinese type Biogas reactors in Sri Lanka (Personnel Communication, Upawansa and Sapumohotti) has been shown and continues to be demonstrated in few functioning plants. This shows the necessity of treating the organic fraction differently.

This illustrates the need of an integrated solid waste treatment according to the constituents present and also taking into consideration the quantity. It is required to carry out the R&D activities on continual basis in order to cope up the changes in society, human behaviour, population and rate of urbanization etc in long run for achieving a proper management of solid waste in the country and afterwards maintaining it. It should be appreciated that some organizations have done some researches on those areas, and Sri Lanka should learn from international experience too. The most important factor is adaptation of technologies developed by others to suit our country's conditions. Literature review reveals that information on the following areas are lacking about the solid waste management in our country;

- Improved technology adaptation according to waste characteristics of Sri Lanka.
- Leachate characteristic study and their consequences due to open dumps.
- New applications out of recyclable materials.
- Environmental, social and health implications of present open dumps/practices.
- Standards on compost and application of compost according to crops.
- New tools to be used in environmental education among the general public and
- Social and health implications among the solid waste-handling workers due to present practices etc.

Figure 1.5 shows the reasons to select the biological treatment and figure 1.6 shows the integrated solid waste treatment components.



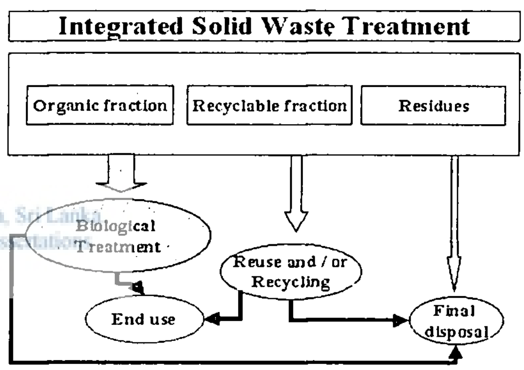


Figure 1.5: Biological treatment options.

Figure 1.6: Integrated solid waste treatment.

The general practice in Sri Lanka for handling the organic fraction of MSW is low rate composting systems. Most have failed due to poor management, lack of knowledge of proper operation, poor product quality, long lead-time, weaker community participation and lack of public awareness. These systems have largely been controlled by default rather than by design. Therefore, it has lost the public confidence on composting. In order to gain the lost confidence on this technology, it is timely required to introduce a new approach, which eliminate the disbelief developed, not only among the general public but also among the potential private sector entrepreneurs.

National Strategy on Solid Waste Management (NSSWM) developed by the Ministry of Environment of the Government of Sri Lanka has focused the management of this growing problem from waste generation to final disposal. However, it is required to facilitate the infrastructure to overcome the present difficulties in implementing the proposed national strategy.

1.4 Waste as a Resource

Resource recovery has been developed informally for the past few years in Sri Lanka for certain type of materials. Scavengers use to collect glass, paper, HDPE, LDPE, plastic, and metal etc. However, this area has to be developed as micro finance enterprises for the low income communities, which encourage the people not only to earn money out of waste, but also some kind of awareness on the environmental management in a positive manner. In this area, Community Based Organizations (CBOs) can play a major role, by identifying the suitable markets and making the necessary links with the communities who collect those materials, awareness on material selection, preprocessing of the material for value addition (washing & separation) etc.

Figure 1.7: Plastic and polythene Figure 1.8: Waste paper

Polythene and plastic recycling is a fairly growing industry at cottage level. However, necessary coordination among the responsible organizations is lacking to the required level. By nature the polythene shows a greater volume than it really exists. However, when it is considered the rural urban sector, it is economically not viable to set up recycling industries based on polythene and plastic locally unless otherwise, it can be collected a fairly significant quantity. However, palletizing can be done and transported to the places where it can be recycled. This would reduce the transport cost as well as preprocessing need at recycling centers while doing a value addition to the raw material produced at the remote areas. Paper recycling is done in large scale (Paper mill) as well as in micro level (hand made paper). This reduces the use of natural resources as well as environmental stress face during the pulping process.

Glass recycling is mainly done at the Ceylon Glass Company. According to them, 40 % of recycled glass (cullet) is used in the manufacturing process of glass. And, they have the capability to go up to the 60% of recycled glass in the process (NSSWM, 2000). All these efforts reduce the use of natural resources, energy; extend the plant life and the environmental safe guard than starting those processes from the basic raw materials. Therefore, resource recovery from waste stream has a crucial role to play, not only in integrated solid waste management, but also in the process of saving the limited natural resources.

1.5 Objectives and the scope of the research

The broad objectives of the research are as follows;

- A review of solid waste management practices in Sri Lanka and the process of composting.
- Identification of Composting strategies and evaluation of them.
- Design of a high rate in vessel composting system.

1.6 Thesis Structure

The thesis structure in general is as follows;

Chapter one describes the general background of the solid waste management in Sri Lanka and highlights the urban waste management issues, problems of mismanagement of solid waste, the need analysis for ISWM, waste as a resource in the context of Sri Lanka, objectives and the scope of this research.

Chapter two describes the Municipal Solid Waste in Sri Lanka in detail, on characteristics and generation of MSW, review of solid waste management efforts, lessons to be learnt and role of Composting in ISMW.

Chapter three describes the literature review done on basic science of Composting, technology of Composting, review of Composting technologies, review of composting applications and Compost as a resource for soil enhancement.

Chapter four describes the Composting system design and utilization by highlighting the selection of the composting technology, basic design of the composting system, feedstock characterization and preparation, process control and final treatment (curing) of compost.

Chapter five describes the BIOCOM-MSW System development with the principles of the system design, system characteristics, operational characteristics and installation.

Chapter six presents the results and the discussion.

Finally the chapter seven describes the conclusions from the study and directions for future work.

Chapter Two

A review of Municipal Solid Waste (MSW) in Sri Lanka

A detailed review on MSW of Sri Lanka would result characteristics and generation patterns of solid waste, efforts done so far, lessons learnt from the past and the role of composting in an integrated solid waste management. This helps to design composting system, which suits to local conditions Therefore, when it is analyzed the characteristics and generation of solid waste, it is required to find the variations of those from region to region or local level in order to understand any significant difference. Further, localized industries would generate area specific substrates (Ex. sawdust; Moratuwa). Though theoretically, all organic matter can be decomposed, it is important to degrade those materials within a reasonable time in solid waste management.

Therefore, identification of each component of waste stream helps to select the most appropriate technology, design the unit operations (sizing), getting required health precautions, capital requirement, site selection and space needed in the treatment facility in a given area. The quantity of waste and annual growth of waste generation determine the capacity and lifetime of the treatment facility, recycling facility and landfill respectively. Therefore, characteristics and generation analysis reveals important information for selecting and designing a method to treat each solid waste component and resource allocation for collecting and transporting the waste. However, standard sampling and statistical methods have to be followed for estimating reasonably accurate values.

2.1 Characteristics and Generation of MSW in Sri Lanka.

Characterization and quantification of solid waste are done prior to selection of suitable technology. Therefore, data on waste composition, density, moisture content, annual growth of waste generation and calorific value of waste are first found. The moisture content and organic fraction of solid waste stream is significantly high and has been shown that a low thermal values for MSW (De Alwis, 1995 and Pathinathar, 1985).

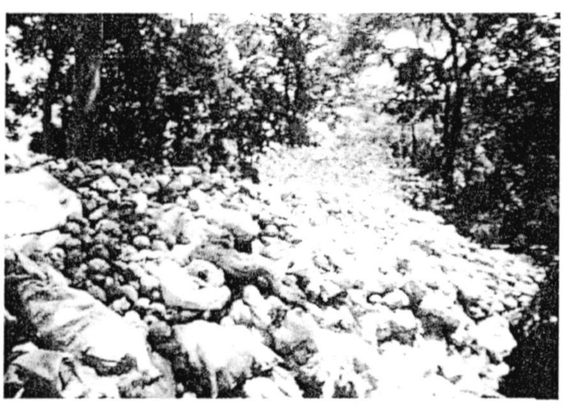


Figure 2.1: Coconut shells and husks

When, it is analyzed the solid waste composition, it can be seen a higher proportion of organic matter. However, all these organic matter cannot be used as the substrate for composting and biogas due to biochemical properties as well as some attitudinal problem. (Use of human excreta as a substrate for composting) Further, it can be seen a higher proportion of king coconut shells, banana stalks and logs, tree cuttings, saw dust, wood chips, paddy husks, coconut husks and shells in the general waste stream.

All these materials consist of higher proportion of cellulose, lignin and hemi-cellulose compounds. Therefore, it is difficult to decompose those materials in a reasonably short time. As it was discussed in the first chapter, mixed waste treatment is a problematic issue for proper waste treatment. It is difficult to formulate a proper feedstock from mixed waste and people reluctant to separate materials at the site.

Highly putrescible materials like food, residues, vegetables, fruits, slaughterhouse & poultry waste, fish waste contained high moisture content and need to treat as quickly as possible. These materials are highly environmental pollutants too. Seasonal variations, cultural activities produce more waste, which are difficult to treat in facilities designed for specific capacity. Most of the time, feed exceeds design capacities and ultimately the technology is blamed.

Figure 2.2: Slaughterhouse waste disposal

It is noted that LAs neither maintain a proper waste inventory nor periodical analysis is done. However, seasonal variations and patterns can be found easily, if that does maintain.

It was assumed that for the analysis, highly putrescible materials as short term biodegradable materials and materials like coconut shells, tree cuttings, and sawdust as long term biodegradable materials. Table 2.1 shows the percentage composition of organic fraction which biodegradable and non-biodegradable fraction by each district (MOFE, 1999).

Table 2.1:District wise waste percentage composition of biodegradable Materials.

Number	District	Waste percentage / %			
		Non-bio degradable	Bio degradable		
			Short	Long	Both
1	Colombo	10.18	68.15	21.67	89.82
2	Gampaha	16.05	49.49	34.46	83.95
3	Kalutara	11.39	44.32	44.29	88.61
4	Galle	18.04	41.75	40.21	81.96
5	Matara	11.19	56.81	32.00	88.81
6	Hambantota	14.06	40.54	45.40	85.94
7	Kandy	12.13	54.83	33.04	87.87
8	Matale	13.18	39.48	47.34	86.82
9	Nuwaraeliya	16.81	60.53	22.66	83.19
10	Kegalle	12.97	45.89	41.14	87.03
11	Ratnapura	10.40	50.02	39.58	89.60
12	Kurunagala	9.72	46.61	43.67	90.28
13	Puttalam	9.49	52.75	37.76	90.51

This illustrates how much organic fraction can be treated easily or how it needs to formulate in order to have optimum decomposition.

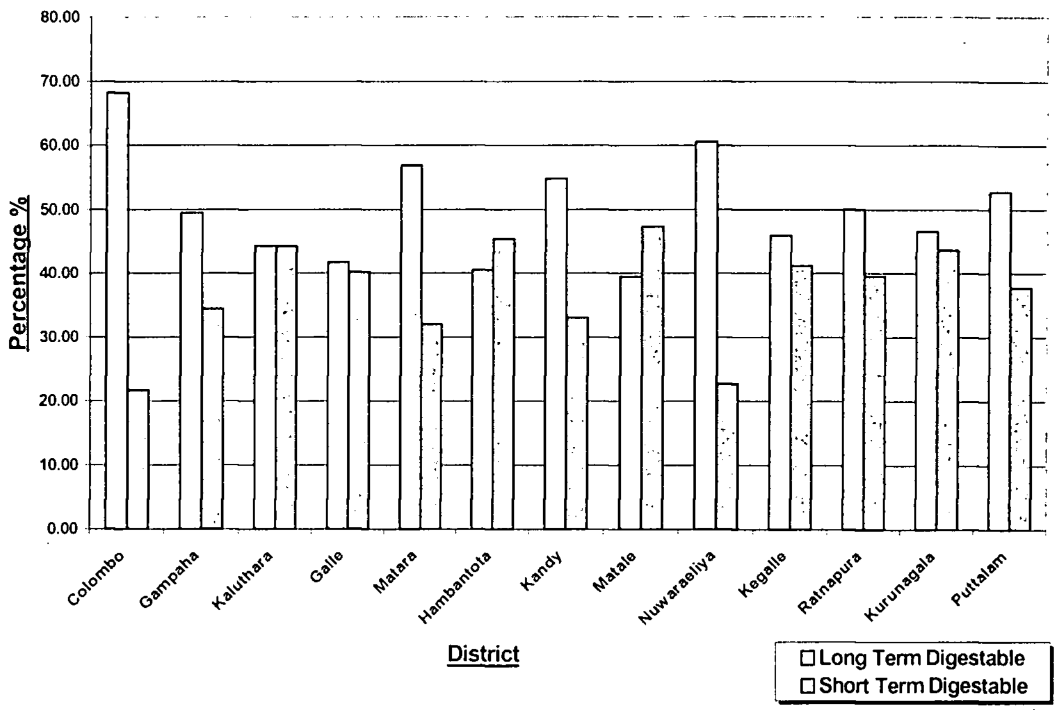


Figure 2.3: Biodegradable Waste Composition by District

Above figure shows, except the Hambantota & Matale districts, the others dominate the short-term biodegradable fraction in the solid waste stream. However, overall percentage of organic fraction has exceeded 85 %. This shows the potential of Sri Lankan solid waste stream for composting.

In order to understand the variations in the rural urban sector, it was carried out the following waste analysis in Atakalanpanna PS, Hambantota and Vauniya UCs. The table 2.2 shows the composition of Atakalanpanna.

Table 2.2 Waste Composition Atakalanpanna Pradeshiya Sabha

Sample	Waste Composition Percentage / %			
	Non – degradable	Degradable		
		Short	Long	Both
Sample 01	6.88	83.60	9.52	93.12
Sample 02	45.59	47.06	7.35	54.41
Sample 03	29.68	15.20	55.12	70.32
Sample 04	31.00	27.00	42.00	69.00
Sample 05	59.69	14.03	26.28	40.31
Sample 06	23.37	13.17	63.46	76.63

This shows how the variations can occur according to the samples. Therefore, it is required to do the sampling properly in such manner, which represents the general solid waste stream in a given area.

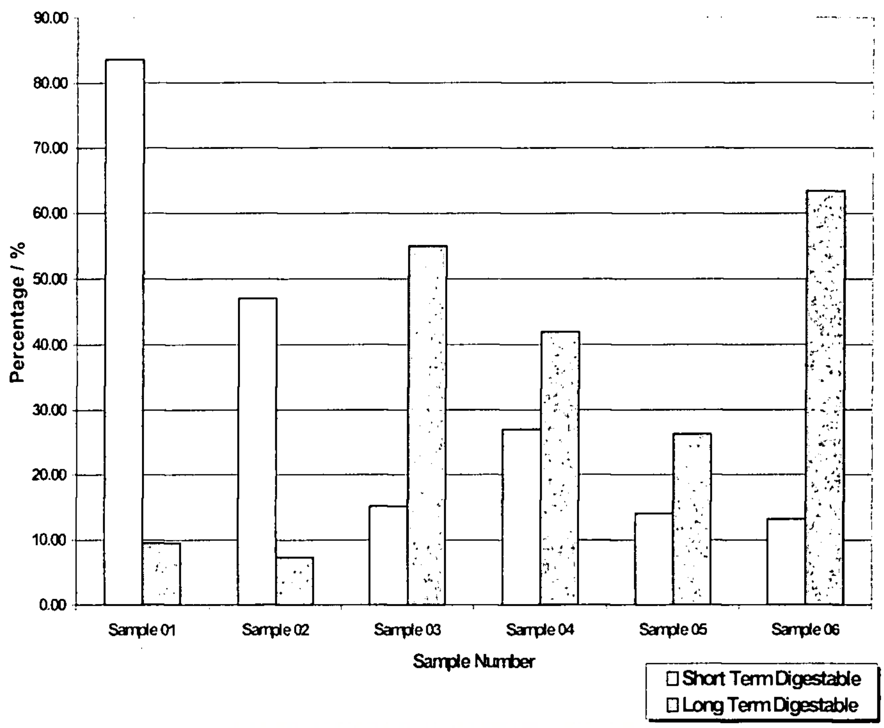


Figure 2.4: Biodegradable Waste Composition of Atakalanpanna Pradeshiya Sabha

According to the waste analysis done at Vauniya Urban Council, it shows a significant difference of composition between the residential and commercial areas. The residential areas dominate the short-term biodegradable fraction while showing the larger variations in sampling.

Table 2.3 Waste composition of Vauniya Urban Council

Sample	Waste Composition Percentage / %			
	Non – degradable	Degradable		
		Short	Long	Both
Residential	4.28	83.93	11.79	95.72
Residential	9.44	70.28	20.28	90.56
Residential	34.62	34.35	31.03	65.38
Residential	60.24	23.21	16.55	39.76
Commercial	4.09	49.18	46.73	95.91
Commercial	6.33	66.67	27.00	93.67
Commercial	22.31	16.31	61.38	77.69
Commercial	14.46	24.70	60.84	85.54

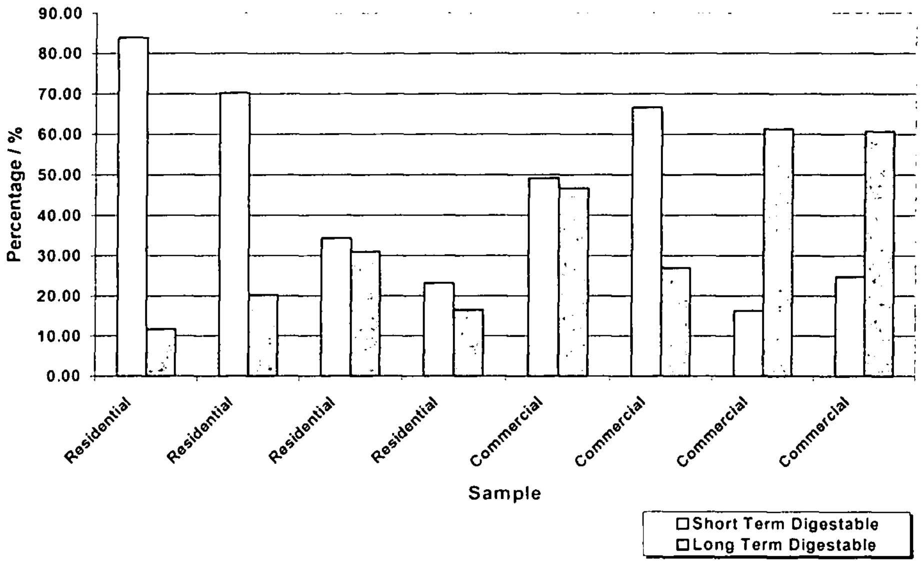


Figure 2.5: Biodegradable Waste Composition of Vauniya Town

The table 2.4 shows the breakdown of the waste percentage as non-biodegradable and biodegradable in residential areas in Hambantota.

Table 2.4 Waste composition Hambantota Urban Council

Sample	Waste Composition Percentage / %			
	Non – degradable	Degradable		
		Short	Long	Both
Residential	21.10	62.31	16.59	78.90
Residential	18.76	79.84	1.40	81.24
Residential	14.50	85.24	0.26	85.50

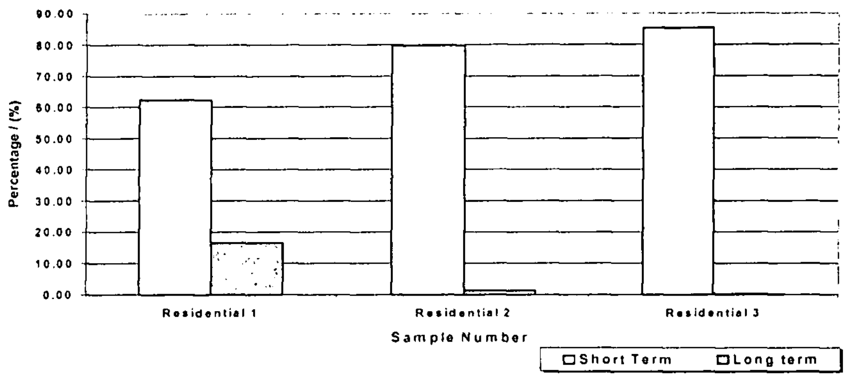


Figure 2.6: Bio - degradable Waste Composition of Hambantota Town

Similar to Vauniya, in Hambantota also, residential areas consist of higher proportion of short term organic fraction. The table 2.5 shows the comparison of each area with the national average.

Table 2.5 Comparison of Bio – degradable Waste Composition

No.	Sample	Bio - degradable Percentage / %		
		Short Term	Long term	Both
01	National average	50.09	37.17	87.26
02	Atakalanpanna	33.34	33.96	67.30
03	Hambantota	75.80	6.08	81.88
04	Vauniya	46.08	34.45	80.53

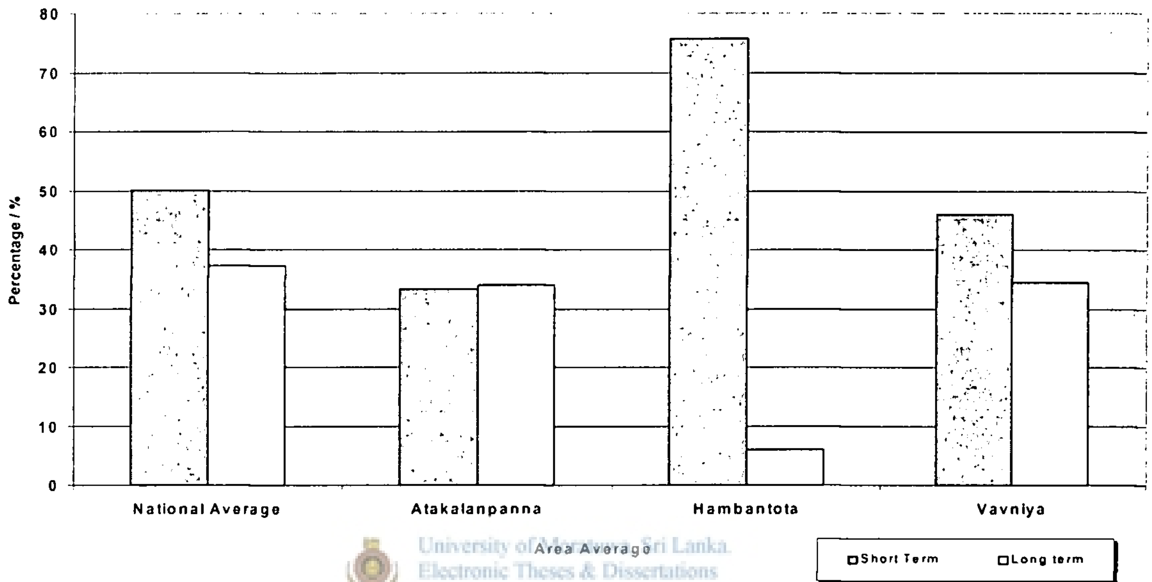


Figure 2.7: Comparison of Biodegradable Waste Composition with National Average

As figure 2.7 shows that the Hambantota short-term biodegradable fraction is greatly varies with the national average. This stresses the need of proper sampling to get representative value.

It is interesting to note that in Sri Lanka, there is no significant difference in composition in urban and non-urban waste. Perhaps, this similarity comes from the fact that the wastes analyzed from non-urban areas are what are collected from rural urban centers. Table 2.6 indicates the solid waste composition in the Colombo city (ERM, 1999).

Table 2.6: Solid waste composition in the Colombo city

No.	**Constituent**	**Percentage / (%)**
01	Organic Matter	84.26
02	Plastic / Polythene	6.61
03	Metal	5.42
04	Paper	1.26
05	Glass	0.29
06	Other	1.49

It has been reported that the calorific value of waste in Sri Lanka is 1000 kcal/kg to 1200 kcal/kg (University of Moratuwa, 1985), which is very much lower than the required value for MSW incineration with thermal recovery. Moisture content varies from 30 % to 80 % depending on the area. Organic fraction exceeds 75% of the total solid waste stream in most of the areas. All these factors lead to biological treatment of waste in Sri Lanka than the other methods adapted by other countries.

In addition to composition analysis, the density variation also gives important factor in transporting the materials. This value shows the compressibility of the waste.

Table 2.7: Waste densities in Vauniya Urban Area

Sample Type	Density (ρ) /(kg/m^3)			
1. Residential	248	220	160	259
2. Commercial	270	210	206	147

Waste densities at Atakalanpanna & Hambantota were 350 kg/m^3 and 330 kg/m^3 respectively. In Vauniya average waste density in residential area was 228 kg/m^3 while in the commercial area was 217 kg/m^3.

The high degree of variability of MSW requires a larger number of samples to be collected and analyzed to estimate its properties with confidence. Therefore, a sample to be representative, it must have a large number of constituents such that which determines the required sample weight. Table 2.8 indicates the solid waste collection by districts (National Database, 1998).

Table 2.8: Daily waste collection by district

District No.	District	Daily Waste Quantity/ (TPD)
01	Colombo	1170.50
02	Gampaha	197.40
03	Kalutara	79.40
04	Galle	75.35
05	Hambantota	21.75
06	Matara	45.63
07	Kandy	162.08
08	Matale	15.98
09	Nuwaraeliya	45.13
10	Kegalle	39.24
11	Ratnapura	77.95
12	Kurunagala	65.79
13	Puttalam	22.85
14	Badulla	147.09
15	Monaragala	22.55
16	Anuradhapura	22.89
17	Polonnaruwa	9.88
18	Ampara	45.75
19	Batticaloa	124.50
20	Jaffna	193.60
21	Trincomalee	87.40
22	Vauniya	10.30

TPD: Metric Tons Per Day

When analyzing the data published by the Ministry of Forestry & Environment (MoFE), it is found that about 88 % LAs collects less than 10 TPD by each. Only four municipalities collect more than 100 TPD by each. Table 2.9 shows the solid waste collection according to the TPD by province.

Table 2.9: Waste collection according to the TPD by Province in Sri Lanka

Province	**No. Of Local Authorities (LAs)**				
	Daily Waste Collection (X) / TPD				
	$10 \leq X$	**$10 < X \leq 20$**	**$20 < X \leq 50$**	**$50 < X \leq 100$**	**$100 < X$**
Western	31	4	4	2	3
Southern	39	2	1	0	0
Central	39	2	0	0	0
Sabaragamuwa	22	2	0	1	0
North - Western	30	1	0	0	0
Uva	26	0	0	0	1
North - Central	24	1	0	0	0
Eastern	29	2	4	1	0
Northern	22	0	3	1	0
Total	262	14	12	5	4
Percentage / (%)	88	5	4	2	1

This result shows how many LAs can operate sanitary landfill economically viable manner in our country. However, most of the LAs can use the biological treatment methods such as Composting and Biogas according to the type of waste and the affordability. In an integrated solution to the problem of garbage requires to have some kind of controlled / engineered landfill for the final disposal of the residues, which can neither be reused nor recycled. However, it can be minimized the adverse effects in controlled / engineered landfills by reducing the quantity of organic waste send to it.

2.2 Review of solid waste management efforts.

Now the decision-makers, town planners, environmentalists have identified the danger we face due to the bad solid waste disposal practices. As some epidemics such as Dengue Fever, filaria, Diarrhea spread in urban areas. Especially, this can be seen in Colombo and it's suburb. Having experience of bad health very often, the general public is also now becoming aware of the need of proper practice of MSW management. Finding solution to this burden problem, various organizations have tried their own solutions. Majority of them have focused on low rate composting systems, which has led to another set of problems due to poor identification of the appropriate technology and site selection etc. Specially, in rainy areas windrows without shelters have led anaerobic digestion of waste piles. Bad smell, polluted water and flies are common experience in those places.

Poor collection methods adapted by the LAs are also a problem in treating the solid waste in a proper manner. It is a common incident in local government bodies, that providing jobs for poor people by politicians in those places, that has led to uncontrollable situation for the management. Hence, this has become an overhead for the LAs to carry out the necessary operations effectively.

2.3 Lessons to be learnt.

Based on the review done Manipura & Jayawardhana (2000), on available local & foreign technologies, it has identified the following reasons, why it has been failed most of the projects implemented in addressing the MSW problem in Sri Lanka.

2.3.1 Poor planning and coordination among the responsible organizations.

This is a major problem observed in various projects visited. Prior to setting up of plants, the required feasibility studies, Environmental Assessments and getting assistance from appropriate institutions have not been followed. Though country has suitable experts in those fields, the proper consultation and advice have not been seek by the implementing agencies. Coordination between Central Environmental Authority, Urban Development Authority and the relevant LA are vital in implementing the projects. Since each institution above regulates related bureaucratic requirements need by the law.

2.3.2 Use of inappropriate technologies.

The most of the institutions have selected the composting as a tool to address the MSW problem. Being an agricultural country Sri Lanka, it seems to be a better option. However in selecting the proper technology, according to local requirements have not been addressed. This is mainly related with the poor coordination, while not following the proper studies on feasibility of technology to be used in those areas.
Ex. In Ratnapura, it has been selected the open windrows, though this particular area is subjected to heavy rain throughout the year.

2.3.3 Long lead-time of composting process.

Improper feedstock formulation, poor technological cum management practices have led to long processing time of waste in the process of composting (Three to four months or more). This increases the storage cost, large space, more manual operations, bad smell and wastewater during the process. Ex. Composting Projects in Ratnapura, Badulla, Bandarawela and Nuwaraeliya.

2.3.4 Weak management structure and lack of accountability

This is another area to be addressed by authorities seriously. The management structure has not been given the proper freedom to administer the operations by political authorities. Though the rules and regulations are available, the members of local government bodies try to achieve their cheep political publicity over these projects. Sometimes some political authorities allow their party members to set up houses or use as commercial ventures where lands are used for disposal sites or treatment plants. This has led difficulty in finding suitable lands for proper disposal or treatment of MSW. The other reason is the reluctant to accept others good work and inability to continue successful work in forward direction. (Attitudinal change is a must for good work.) Transferring of good officers to others places, once the government is changed has also led to fail in some projects. This would be a common political scenario in developing countries. Further, continuous enthusiasm lacks in the project operators. Ex. Nawalapitiya Urban Council Bio Gas/Composting Project

2.3.5 Low quality of the products.

This is again related with the selection of inappropriate technology and poor process management and contamination of foreign materials during the collection and processing. It is important to maintain the required quality standards in order to find a good market for the compost. Especially, amount of sand contain per 1 kg of compost has been so large in some of the products available in the market. (In one case 400 g of sand per 1kg of compost was reported) this has created lot of marketing problems. Ex. Badulla, Ratnapura

2.3.6 Large pieces are fed to composting plants without size reduction.

One main reason to long decomposition period of composting is, no size reduction of waste is done. But this can be improved by using a shredder to a greater extent.

2.3.7 Insufficient cooperation from the residents, administration and workers.

Lack of education on waste management among the general public, administration and workers has ruined the situation. This should be teamwork. Therefore, public participation in proper waste management plays a vital role. Introduction of source separation, advantages of proper waste management related to good health, income out of the waste they generate, introduction of the concept of reduce, reuse and recycle etc have to be included in awareness among the stakeholders.

2.3.8 Less attention to waste handling workers by the administration and general public.

One important link of any solid waste management project is the workers. However the proper attention has not been put on this important link by many authorities. Proper health security would ensure the proper operation of projects in addition to the motivation to do the job in the correct way. These collecting workers do a great work in order to keep our environment in healthy manner. Therefore citizens who enjoy this have a responsibility of assuring their dignity.

2.3.9 Lack of source separation and poor collection methods.

Irrespective of the technology to be employed in the treatment process, the source segregation plays a major role. Hence this saves time and money in processing waste at the plant. But currently this does not practice in Sri Lanka. However some pilot projects started and showed some mix successes (Maharagama Pradeshiya Sabha).

2.3.10 Use of inappropriate vehicles / machinery.

When it is selected, the required vehicles and machinery, the operation and maintenance cost have to taken into account while finding the suitability of these to local conditions. In some cases, though the vehicles and machinery are received as grants or donations by various donor agencies. They have become an additional overhead for some LAs in O&M.

2.3.11 Recycling has not been followed wherever possible.

The main attention has focused on the biodegradable materials. The rest of the parts i.e. plastics, polythene, paper, glass and papers can be recycled. In this process, it is due responsibility of the project officer making necessary coordination among the suitable buyers for recycle materials. In most of the projects, sufficient attention has not been put on this regard. Therefore, they have met problem in marketing recyclable materials.

2.3.12 Poor identification of suitable sites to set up plants.

When selecting sites most of the implementers have not put their proper attention for the social and environmental impacts. Sometimes residential areas have been selected for open systems. This has led to strong public opposition against projects. Ultimately projects are abandoned with large sum of money as a waste. Ex. Nuwaraeliya Composting Project (Rs. 18.26 M)

2.3.13 No proper waste characterization and generation have been assessed

It is required to identify the indicative quantity of waste, waste composition, identification of waste generating sources etc prior to selecting a suitable technology to treat the MSW. In most of the cases, it has not been followed a proper study to ascertain those basic parameters.

2.4 Role of Composting in ISMW in Sri Lanka.

As discussed earlier, it is clear that our organic fraction consists of higher quantity of organic waste, high moisture content, low calorific value and non-separated waste. This all leads to biological treatment than the other options available. Then it is a question of selecting the type of biological treatment. Factors like space available, type and quantity of waste, public perception on waste management as well as the products, capital available, operation & maintenance cost, market price of products, location of the site, technical affordability (level of technology), rules & regulations and rate of conversion of the waste environmentally sound manner decide the appropriate option.

It is important to find out, how effectively that compost can be made use in soil erosion reclaimation, organic farming and other agricultural practices. In order to understand this, following case studies can be used.

According to report by UNEP status of environment: Sri Lanka 2001, land is the one of the heavily threatened natural resource in Sri Lanka. Degradation of land due to soil erosion is of much concern because of its consequences on agriculture, which is a major contributor to the country's GDP. It is estimated that about 5-10 mm of topsoil is lost every year. In the hill country, where several large rivers originate and critical watersheds are located, erosion is acute.

The table 2.10 shows the land use distribution as well as the importance of land usage in agriculture in our country (UNEP, 2001).

2.10: Land use by types in Sri Lanka.

Land Use Types	Extent in Hectares	Percentage/ (%)
Built up Lands	29,190	0.5
Agricultural Lands	3,710,880	59.5
Forest Lands	1,759,840	28.2
Range Lands	593,520	9.5
Wet Bodies	61,810	1.0
Barren Lands	77,480	1.2
Total	**6,232,720**	**100**

Source: UNEP, 2001

Several direct and indirect factors cause soil erosion. The cultivation of erosive crops such as tobacco, potatoes and vegetables has led to severe erosion particularly in hilly areas. It has been estimated the cost of damage in soil erosion (hill country alone) is about Rs. 3.4 billions (UNEP, 2001).

2.11: Soil Erosion rates under different Crops in Nuwara Eliya District.

Crop	Erosion Rate / (mt/ha/yr.)
Tobacco	70
Capsicum	38
Carrots	18

Source: UNEP, 2001

Now, organic farming is fairly growing area in the country. This has been developed from small scale to large-scale export oriented agriculture. Therefore, it is inevitable the increase of the demand for the organic manure in future.

It is needed to increase the Cataion Exchange Capacity (CEC) of soil. Compost could be used for this effectively. Further, soil conditioner increases the water holding capacity of the soil.

This situation illustrates the importance of the compost in agricultural areas of the country. Therefore, soil conditioner has a greater role to play not only as an output of solid waste management but also in land reclamation. Then Composting and Biogas technologies can effectively be used in order to meet this requirement. However, Biogas technology needs more closer process control and higher capital, when compare with the composting. According to the type of substrate and other factors determining the technology, Composting can be selected as an appropriate technology. It is evident that composting could be done in a wide range from micro scale (home composting) to medium and large-scale operations.

Chapter Three

Literature Review

3.1 Basic Science of Composting.

3.1.1 What is Composting?

Finstein & Hogan, (1991) defined, Composting is a process based on the phenomenon of microbial self-heating of organic assemblages. The material being composted is its own matrix, in which a moist solid phase (organic particles) interfaces with a gas phase (interstitial air).

De Bertoldi et al (1990) described, the Composting as a controlled biooxidative process that involves a heterogeneous organic substrate in the solid state, evolves by passing through a thermophilic phase and leads to production of carbon dioxide, water, minerals and stabilized organic matter (compost).

Further De Bertoldi (1990) stated that compost (product) is the stabilized and sanitized product of composting (process), which is beneficial to plant growth. It has undergone an initial rapid stage of decomposition and it is in the process of humification.

Composting is the process of biodegradation of organic matter in which the process of chemical breakdown of a substance to smaller products caused by microorganisms or their enzymes (Pilapitiya, 1988).

Therefore, it can be understood that the Composting is a process of converting the readily biodegradable organic fraction of the waste stream, in a controlled manner in the presence of oxygen, into stabilized humus like organic residue that is suitable for use as a soil conditioner.

Although composting is essentially an aerobic process, anaerobic decomposition is known to occur in microenvironments of the heterogeneous, oxygen poor matrix of compost itself (Blanc et al, 1999). Therefore, composting either can be aerobic or anaerobic according to the oxygen amount available for the decomposition. If aerobic microbes carry out the process, then it is called the aerobic composting. When it carries out by the anaerobic microbes, then it is called the anaerobic composting. Usually, the process is defined according to the predominant group of microbes act on the substrate according to the aerobic or anaerobic conditions prevailing. However, the aerobic composting is much faster than the anaerobic composting, and hence, it is preferred in solid waste management (Polpressart, 1998).

Schulze (1962) explained that the aerobic decomposition normally proceeds through a series of distinct phases; (i) fermentation, (ii) acid formation, (iii) thermophilic activity and (iv) temperature decline. During the first two phases, mesophilc microorganisms such as yeast and bacteria are predominant and the temperature of the decomposing material increases from ambient to 45° C. Thermophilic bacteria characterize the third phase, which produces temperature from 45° C to 71° C due to their intense respiration. In the fourth phase, actinomycetes and fungi take over, accompanied by a decline in temperature back to ambient. Under the properly controlled conditions, the composting process could be run into thermophilic phase avoiding the initial two phases. This eliminates the lag period associated with two initial phases and hence it leads to a rapid decomposition of organic waste materials. Figure 3.1 shows the temperature profile and organic matter loss during composting (Rynk, 1992).

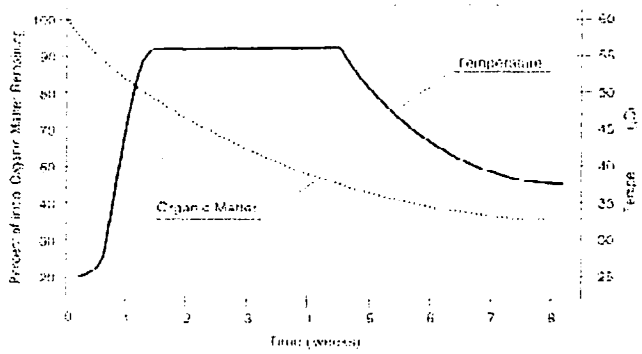


Figure 3.1: Temperature profile and organic matter loss During composting

3.1.2 Critical Parameters

The composting process at the microbial level involves several interrelated factors, i.e. metabolic heat generation, temperature, ventilation (oxygen input), moisture content and available nutrients (Beffa et al,1998).

a. Microorganisms

A large variety of mesophilic, thermotolerant and thermophilic aerobic microorganisms (including bacteria, actinomycetes, yeasts, molds and various other fungi) have been reported in composting (Beffa et al, 1998). These microbes are active at different moments in the process of biodegradation. Hence, the activity of microorganisms in the biodegradation process is a function of many factors such as inorganic nutrients, pH, microbial population density, diversity and chemical structure of the organic compounds. The initial rapid increase of temperature involves a rapid transition from a mesophilic to a thermophilic microflora. Mesophilic microbes are partially killed or poorly active during the initial thermogenic stage (temperature between 40° C to 60° C), where the number and species diversity of thermophilic / thermotolerant bacteria, actinomycetes and fungi increases. The optimum temperature for thermophilic fungi is 40° C – 55° C, with a maximum at 60° C – 62° C. Fungi are killed or are present transiently as spores at temperatures above 60° C. Fungi seem to have a better ability to degrade the hydrocarbons of complex structures or long chain lengths. Although incomplete metabolism is generally associated with fungi, actinomycetes degradation results in intermediates, which can be metabolized in the presence of other organisms. Among the fungi, the mold *Aspergillus fumigatus* has a special significance; due to its capacity to degrade almost all components of organic waste (sugars, fatty acids, proteins, cellulose, pectin, xylane etc.). Its thermotolerance finds ideal proliferation conditions in young compost. Their optimal growth is at 37° C; good growth rate is between 30° C to 45° C and maximal growth is at 52° C are reported by Beffa et al, 1998. *A. fumigatus* conidia can survive at temperatures of 55° C – 60° C for fairly long period and unfortunately they are also known as opportunistic pathogen and allergen. It is strongly cellulolytic, but it also can grow on hydrocarbons in aviation kerosene, and it can enter the lungs as inhaled spores, causing allergies or growing in the lung cavities, causing aspergillomas. (http://helios.bto.ed.ac.uk/bto/microbes/apical.htm#crest). Figure 3.2 and figure 3.3 show some active fungi at thermophilic temperatures.

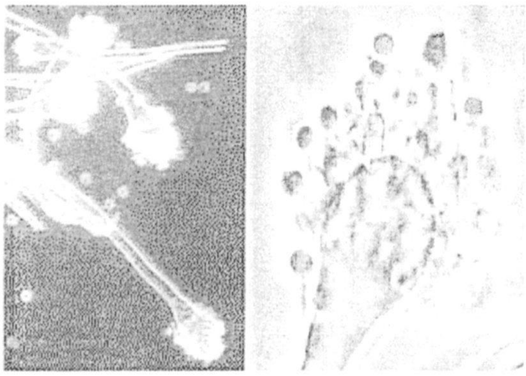


Figure 3.2: *A. fumigatus*-common fungus in Compost 55°C.

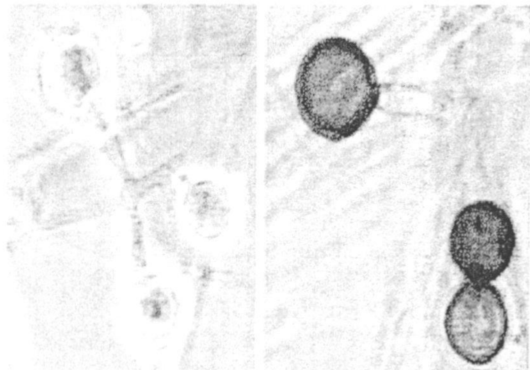


Figure 3.3: *H lanuginosus*–Grows at 30 to 52-52

Miller (1989) claimed nonfilamentous bacteria, which require water for mobility, are primarily responsible for the most active, early phase of composting. During active, high temperature stages, composting is primarily a bacterial ecosystem dominated by the members of the genus *Bacillus*. Thermophilic bacteria are very active at 50° C - 60° C. High temperatures (>60°C) are often considered to decrease dramatically the functional diversity. Beffa et al (1996) showed thermophilic oval-spore-forming bacilli are very active during composting, when the temperatures are between 50° C and 65° C. However, temperature between 65° C and 80° C were usually reached during the thermophilic phase.

Composting time depends on the biological cycles of the microorganisms involved and their replication time, which is conditioned by environmental factors and genetical constitutions of the those microorganisms (Bertoldi et al 1990). Ishii et al (2000) pointed out the monitoring of the microbial succession is important in the effective management of the composting process as microbes play key role in the process. Further appearance of some microbes reflects the quality of maturing compost.

b. Raw Materials and Particle Size

Morisafi et al (1989) pointed, when organic materials are composted, carbon components in them are used partly as energy sources in catabolism and rest is incorporated into cellular materials in accordance with use of nitrogen sources. If the nitrogen amount in the raw materials is in excess, ammonia is liberated and hence, nuisance odor is occurred during composting while losing the nitrogen. Haug & Haug (1977) said that Composting has been applied to materials such as municipal refuse, agricultural residues, animal litters, plant trimmings and dewatered sludge from industries and municipalities. Readily degradable materials decompose easily whereas cellulose, hemi-cellulose and lignin contained materials decomposed rather slowly. Suggested C/N ratio is 30-35 to optimize compost processing, since a lower C/N ratio indicates a potential loss of excess nitrogen through ammonia volatilization. Therefore, it is needed to keep C/N ratio in the matrix around 25 – 35, while it is given the optimum results by the ratio of 30. Further, it is required to mix the substrate properly, which gives the homogenized C/N ratio prior to composting the matrix.

Fraser & Lau (2000) showed that both feedstock degradability and nitrogen retention are greater when more readily degradable carbon is present.

Large particles resist degrading due to lower specific surface area exposed to the microbial activities (enzyme transport, inter-particle material transport; I.e. microbes to materials and vice versa). Too small particles decrease the porosity in the matrix. Then, it is developed the anaerobic conditions, which slows down the decomposition while producing compounds such as dimethyl sulfide (DMS) and methyl mercaptan (MM).

c. Moisture

Moisture content is a convenient and useful process control parameter in composting, but it is a poor means of comparing the water status of dissimilar organic materials as this relate to microbial activities (Suler and Finstein, 1977). Miller (1989) pointed out that the previous composting investigations have used gravimetric water content (i.e. weight of water over total weight), is a crude tool providing little fundamental insight. But, water activity (a_w) which is again ineffectual for describing water-related phenomena in matrix systems; because it fails to distinguish different types of water interactions and is quite insensitive in moist systems. However, it is often found that for solid waste composting moisture content of 50 % to 60 % is suitable, where as 70 % is too high. Compounds insoluble in water have shown difficulty in biodegradation mainly due to their inaccessibility to microorganisms. Further, Haug & Haug (1977) stated higher the moisture content of the organic materials leads to keep higher volume in order to assure adequate aeration. Therefore, substrate like dewatered sludge cake, which has high moisture content, is lack of porosity and tend to compact, hence needs to dry the materials during composting. By controlling the moisture content, adding some bulking materials helps not only to have the optimum moisture content for microbial activities, but also helps to keep the structural integrity of the composting matrix. Earlier Schulze (1960) argued that it can be controlled the moisture in the matrix by maintaining the just enough aeration conditions, hence the amount of water carried out by the airflow is nearly equal to the amount of water produced by the oxidation process. According to Seymour et al (2001), maintaining adequate moisture content during the In-vessel process was a concern with the aeration treatments. Moisture content of 40 % – 65 % was the reasonable range for rapid composting, while 50 % – 60 % moisture content is the preferred range. They stated that within the research vessel, there was not a way to add moisture uniformly to the composting mixture. Therefore, initial moisture content was increased in order to prevent over drying and possible inhibition of the process. This could be applied in static In-vessel composting systems preferably. Although the moisture contents were different for the different depths within the vessel, samples taken near to bottom (plenum) did not fall below 30 % moisture content at the end of 28 days cycle. Table 3.1 shows the recommended moisture content for different composting materials, as stated by Haug & Haug (1977).

Table 3.1 Maximum recommended moisture content for various composting Materials

Type of waste	Moisture content % of total weight
Straw	75 – 80
Wood (sawdust, small chips)	75 –90
Rice hulls	75 – 85
Municipal refuse	55 – 65
Manures	55 – 65
Digested or raw sludge	55 – 60
Wet waste (lawn clippings, garbage etc)	50 – 55

Source: Haug & Haug, 1977.

d. Aeration (Oxygen)

Schulze (1960) pointed out that composting is an aerobic process; hence air or oxygen has to be supplied to the decomposing material in order to achieve the high temperatures and the rapid degradation of organic substances, which are characteristics of this process. The most of the technical rules for composting are dictated by the need of a constant air supply to all parts of the organic waste material to be stabilized. Higher air supply rates results the higher residual oxygen in the matrix and causing greater heat losses due to increased evaporation. Miller & Finstein (1985) showed the aeration must suffice to meet the peak demand for the ventilation; i.e. highly putrescible waste requires a relatively large blower capacity. The pressure-induced mode of ventilation is preferred over the vacuum-induced mode, because it removes heat and vapor more efficiently. The use of more air reflects more extensive waste decomposition. Seymour et al (2001) suggested that the 24 – hour maximum aeration volume was necessary for only the first 3-5 days. After the first five days, the air volume needed for adequate aeration could be reduced as much as 50 % while maintaining a suitable oxygen concentration for the rest of the in-vessel phase.

e. Temperature

The temperature is a function of the accumulation of heat generated metabolically; simultaneously the temperature is a determinant of the metabolic activity. Initially, the higher temperatures stimulate mesophilic growth, but as inhibitive levels are reached, this leads to a self-limiting condition. Due to higher temperature, now induces the thermophilic growth, the pattern is repeated in a second, hotter stage. At peak, thermophilic temperatures, the metabolic activity is relatively slight. Therefore, the system is prone to self-limit via the excessive accumulation of heat. The thermophilic range, activity is greatest at 52° C to 60° C and that a steep decline starts above this upper boundary (MacGregor et al, 1981). When composting is not controlled, the temperature due to self-heating would exceed the limit of 70° C. If temperature persists long, then it inhibits the microorganisms present in the matrix such as actinomycetes, fungi and non-thermo resistant microorganisms. The loss of microbial population retards the composting and particularly microbial transformation of long-chain polymers such as cellulose, hemicellulose and lignin. Essentially mesophilic fungi and actinomycetes degrade these materials.

3.1.3 Compost Maturity

Maturity is the degree or level of completeness of composting. This means that raw starting materials (feedstock) have been sufficiently decomposed under controlled moisture and aeration conditions which results in a stable organic amendments product (CCQC, www.ccqc.org) Lasadri et al (2000) said, compost stability determines the degree of decomposition of biodegradable matter. i.e. to what extent composting process has progressed. According to Stentiford 1993, there is no simple and reliable test for the compost stability. According to CCQC, immature compost may contain or produce high amounts of free NH_3, certain organic acids, or other water-soluble compounds, which can limit seed germination and root development. Morisaki et al (1989) stated that nitrogen transformation during composting has been related to maturity of compost. Lasaridi and Stentiford (1999) showed that the self-heating potential and germination index (GI) could be used as suitable indicators of stability, as they correlated well with compost age and respiration. However, Fraser & Lau (2000) claimed that organic matter loss can be significant during the curing phase, hence the importance of curing phase to the entire composting process.

a. Pathogen Inactivation

Beffa et al (1998) pointed out that composting at industrial scale can pose problems of occupational safety, due to occurrence of aerosols containing allergenic / pathogenic micro organisms and toxins. According to USEPA (1993) part 503, it is required the substrate to be exposed to temperatures above 55° C for at least three days, to ensure the pathogen reduction to an acceptable level. However, the outer parts of composting piles are not subjected to this required temperature. In turned systems, there is a risk of recontamination of the materials, which has not been sanitized properly. Meekings and Stentiford (1999) stated that the possible recontamination is not considered to affect the product safety, as other factors also contribute to pathogen reduction during composting. Beffa et al (1998) claimed that the range of temperature of 50° C to 60° C does not guaranteed the potentially pathogenic and / or allergenic microbes. It was shown the possibility to compost at higher temperatures (60° C - 75° C) for a longer period of time, but not exceeding 80° C. Hence, the composting process can be performed with a better destruction of potential human pathogens and allergenic molds, as well as phytopathogens and seeds.

b. Temperature

It does not completely clear that how and why pathogenic organisms are destroyed during the composting process. High temperatures are presently assumed to be the primary destroyer of pathogens, including helminth ova, but microbial activity is also thought to have an involvement in the destruction of pathogenic organisms (Finstein, et al., 1987; Golueke, 1977; Stentiford 1987).

Table 3.2: Thermal death points of some common pathogen & parasites

No:	Organism	Temperature & Time required to kill
1.	*Salmonella typhosa*	No growth beyond 46°C; death within 30 minutes at 55 - 60°C.
2.	*Salmonella* spp.	Death within 1 hour at 55°C; death within 15 – 20 minutes at 60°C.
3.	*Shigella* spp.	Death within 1 hour at 55°C.
4.	*Escherichia coli*	Most die within 1 hour at 55°C, and within 15 – 20 minutes at 60°C.
5.	*Entamoeba histolytica* cysts	Thermal death point is 68°C.
6.	*Taenia saginata*	Death within 5 minutes at 71°C.
7.	*Trichinella spiralis* larvae	Infectivity reduced as a result of 1-hour exposure at 50°C; thermal death point is 62 - 72°C.
8.	*Necater americanus*	Death within 50 minutes at 45°C.
9.	*Brucella abortus* or *suis*	Death within 3 minutes at 61°C.
10.	*Micrococcus pyogenes* var. *aureus*	Death within 10 minutes at 50°C.
11.	*Streptococcus pyogenes*	Death within 10 minutes at 54°C.
12.	*Mycobacterium tuberculosis* var.*ominis:*	Death within 15 – 20 minutes at 66°C, or momentary heating at 67°C.
13.	*Corynebacterium diptheriae*	Death within 45 minutes at 55°C.

Source: Polprasert, 1989

3.2 Technology of Composting.

Technology of composting basically addresses how the composting is done (open / in vessel or vertical / horizontal) and the way process is controlled.

3.2.1 Process configuration and control strategy

Spontaneous composting occurs in nature. However, these processes are slow, discontinuous and heterogeneous. Bertoldi (1990) has stated to make composting suitable for industry of solid waste management, three fundamental points have to be met as follows.

1. Brevity of the process & low energy consumption
2. To guarantee a standard end product not only safe for agriculture but also of satisfactory fertilizing value and
3. Hygienic safety of plants and end products.

In order to meet these criteria, spontaneous composting cannot be accepted. It must be controlled so that it guarantees the low cost and high quality end product. Therefore, several types of systems have been developed in various parts of the world according to their climatic, social and scientific & engineering expertise available. Basically all these systems have tried to optimize the conditions, which directly influence the growth and metabolism of microorganisms that carry out the process.

According to Miller & Finstein (1991), the geometry of the composting mass, equipment & machinery for ventilation, turning and materials handling, structures to enclose the composting area or vessel to hold the composting mass are referred collectively as ***process configuration***. Process organization involves managing the underlying composting microbial ecosystem. This determines system behaviors whether by plan or default, is collectively known as ***process control strategy***. Therefore, it is understood that the strategy is a unifying concept whereas configuration represents a particular mode of implementation the process. Hence, control strategy refers to the physical, chemical and biological interactions, which play regardless of process configuration. Finstein et al (1991) describes following factor in designing a composting systems.

- Heat is generated at the expense of waste, predominantly through aerobic microbial respiration.
- Ventilation serves to supply O_2, and to remove heat and CO_2, removal of water accompanies that heat.
- Heat generation is not appreciably suppressed at O_2 levels > 15 % v/v.
- The threshold to appreciable temperature self-limitation in the thermophilic range is approximately 60° C.
- Heat loss through radiation is negligible.
- 85 % of the ventilation associated heat removal is through evaporative cooling and sensible heating of the air.

High rate systems decreases the size of the treatment facility, hence the need for payload capacity. Intensive aerobic, microbial action disfavors human and plant pathogens and odor generation. Therefore, rate maximization is a basic tenet (Finstein et al 1991).

The free air space of a composting mixture is important in determining the quantity and air movement of air through the mixture (Haug, 1978). Further Haug (1978) showed that stoichiometric oxygen demand is less than the air requirement for drying means that compost can be separated from drying by controlling the air supply. Since the evaporative cooling is the large energy demand imposing on the composting system. Thereby controlling the air supply, evaporation of water can be controlled within the energy budget in the composting system. Fraser & Lau (2000) claimed that successful examples of automatic control of moisture content are not common, perhaps due to the relative difficulty of in-situ moisture measurements. Further, moisture content has been typically either set initially by feed conditioning, controlled by manual water addition or maintained by open loop control of water addition.

3.2.2 Different Control Strategies

In composting, the basic process control objective is to maximize microbial activity at the expense of the waste being treated. Schulze (1962), showed composting process could be optimized using reliable automatic temperature control coupled with air supply control. Rational composting process control involves the interrelated factors of heat output, temperature, ventilation and water removal / addition (MacGregor et al, 1981). Fraser & Lau (2000) showed that number of technical challenges facing mid- and large- scale composting operations, including odor management, quality control, process & economic efficiency and improved worker health & safety in designing various composting systems. Though the most composting odor is treatable, reduction of source odor can reduce the sizing and cost of treatment facilities.

a. The Beltsville Control Strategy

Aeration of static pile is provided by a timer which turns the blower on and off on a predetermined schedule (Fraser & Lau 2000). This maintains an oxygenated condition in the pile, 5 % to 15 % oxygen (O_2), through minimal ventilation. Hence, it can be easily achieved because the composting mass tends to accumulate metabolically generated heat excessively, leading inhibitively high temperature. Then, consumption of oxygen and other microbial activities are suppressed. Consequently, slight ventilation on a fixed schedule maintains O_2 consumed (Miller & Finstein, 1990).

Figure 3.4: Blower Control Logic of Beltsville Strategy

With timer control mean and peak use differed slightly, because blower schedule is predetermined. The simpler fixed aeration strategy seemed to provide for increased pathogen reduction, but it may also increase the time required to produce equivalent quality compost compared to temperature limiting control strategies (Fraser & Lau, 2000).

b. The Rutgers Control Strategy

The implementation of the temperature non-self-limiting principle in static pile configuration is named Rutgers process. Finstein et al (1985), stated this method maintains a temperature ceiling that provides a high decomposition rate through on demand removal of heat by ventilation (thermostatic control of a blower.) In this strategy, the implementation is via temperature feedback control of a source of forced air. When the temperature reaches a set value, the ventilation is demanded to cool the material. The demand is time dependant and the source of air must be met with the peak demand exerted during a processing cycle (Hogan et al, 1989). Figure 3.3 shows the blower control logic of the Rutgers Strategy.

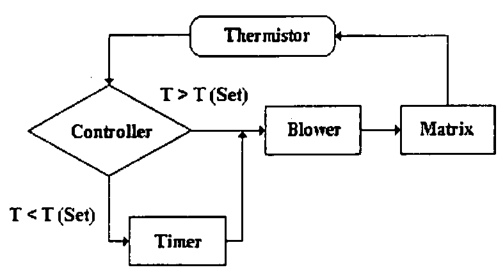


Figure 3.5: Blower Control Logic of Rutgers Strategy

The intensive drying was occurred due to heat removal by the latent heat of vaporization of water. Heat loss was happened by sensible air temperature increase and established a temperature gradient in the composting matrix along the airflow direction.

As Macgregor et al, 1981 showed, the ventilation provides O_2 for aerobic respiration and removes heat (hence water: vaporization) although the temperature feedback control system responds directly to temperature; indirectly the response is to microbial heat output and oxygen consumption. This is because the temperature is a function of heat output, which in turn is a function of aerobic respiration. The feedback approach to control thus assures a well-oxygenated condition, as blower demand and oxygen demand are indirectly linked. Miller & Finstein (1990) have recognized that it is required the mixing and abrading the material even in the static piles. Linear temperature feedback is preferable to oxygen feedback in that it does not require expensive oxygen sensors (Fraser & Lau, 2000). The Rutgers strategy has a limitation in which does not supply optimal oxygen at all times. However, Finstein & Hogan (1993) claimed oxygen feedback might not be necessary due to the fact that temperature feedback control maintained a high level of oxygen resulting from temperature-induced aeration. But Fraser and Lau (2000) demonstrated the Rutgers Strategy led to very low oxygen concentrations early in the composting process, which produce higher concentrations of odorous gas. Finstein et al (1985) claimed that the Rutgers strategy yield high rate composting which decomposes approximately four times the waste in half the time.

c. Oxygen Feedback Control Strategy

De Bertoldi et al (1988) recognized, when ventilation is controlled in order to maintain the O_2 level in the internal atmosphere of the composting mass between 15 % to 20 % gives the better results. This is in terms of process control, quality of end product, low energy consumption and hygienization of compost. Fraser & Lau (2000) also showed that oxygen content was maintained more consistently using oxygen feedback or linear temperature feedback algorithm. Further, they claimed that Nitrification appeared to be greater, when using an aeration control algorithm that supplied oxygen more in accordance with the demand. i.e. oxygen feedback control strategy gives a better Nitrification.

d. The Linear Temperature Feedback (modified Rutgers) Strategy

As Fraser & Lau (2000) stated, the modified Rutgers Strategy combines both temperature and oxygen feedback control algorithms. Hence, when the temperature exceeds the set point, the blower works continuously; and at temperatures lower than the set point, the blower is controlled by the oxygen level. Similarly, when the oxygen level drops below the oxygen set point, the blower works continuously; and when the oxygen level is above the oxygen set point, the blower operates on a low duty cycle timer. Further, the modified Rutgers Strategy is more consistent compost oxygen concentration compared to the temperature feedback and may have caused an increase in nitrification.

3.2.3 Comparison of Different Control Strategies

The table 3.3 shows a comparison of different control strategies as de Bertoldi et al (1990).

Table 3.3 Comparison of different technologies

Parameter	Control Strategy		
	Beltsville	**Rutgers**	**O_2 Feedback**
Process configuration	Unenclosed static piles.	Unenclosed static piles.	Enclosed bioreactor
Process control objectives	Maintain an oxygenated condition.	Maintain the outlet air enthalpy corresponding to 60° C.	Maintain O_2 level between 15 % to 20 %.
Blower control	Fixed	Variable: Temperature feedback.	Variable: O_2 feedback
Blower operation mode	Vacuum - induced.	Forced pressure.	Forced pressure.
Drying tendency	Slight	Substantial	Regular
Processing time	Long	Short	Medium
Energy consumption	Normal	High	Proportional to O_2 demand.
Decomposition	Slow	Fast	Fast
Pathogen reduction	Substantial	Good	Good

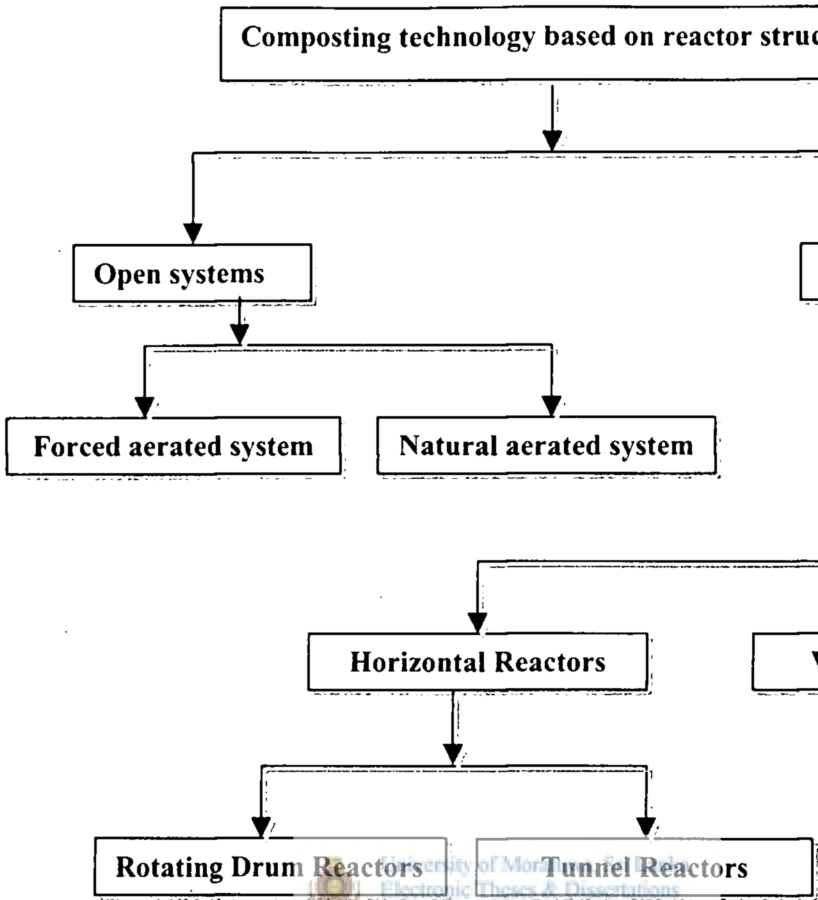
Source: Bertoldi et al, 1990

According to Hogan et al (1989) both at lab and field scales, during the initial period of scheduled based-line ventilation, the temperature ascended to the set point level and engaged feedback control. The temperature persists at a set point level for some time and then gradually descended. The demand for ventilation increases and then decreases eventually ceased it disengaging the feedback control. In field scales the wetness in the matrix is patchy while in lab scale it is more uniform. Oxygen feedback control strategy used a processing time longer than the Rutgers, but shorter than the Beltsville. Energy savings could be realized, since aeration is provided only when oxygen demand is high, and there is no agitation, but the potential for excessively high temperatures remains (Fraser & Lau 2000).

MacGregor et al 1981 stated that the need to integrate physical and biological factors and stressed the thermodynamic behavior is a direct consequence of the heat output – temperature interaction.

3.3 Review of Composting Technologies.

Compost is an ecosystem, which responds strongly to changes in physical factors that select for microbial activity. In order to meet this, different reactor structures have been built. The composting activity can be profoundly affected by physical factors, such as temperature, aeration, particle size and moisture content. Therefore, composting engineering has developed various types of reactors from open systems to closed system according the degree of process control required, space affordable, how quickly matrix needs to be decomposed, capital employable and location of the system. The figure 3.6 shows the categorization of composting technology based on the reactor structure.



* All in-vessel systems are forced aerated.

Figure 3.6: Categorization of composting technologies

3.3.1 Vertical Reactors

These reactors are generally over 4 meters and could be continuous or batch systems. Discontinuous vertical reactors consist of different levels not more than 2 or 3 m and therefore have no advantages apart from the high cost of the plant and maintenance.

a. New Zealand Vertical Unit

In New Zealand system (Shown in figure 3.7), feedstock is fed to the blending box, which serves to create a homogeneous mix of bulking agents (if needed) and feedstock. Feedstock is transferred to the top of the unit by a series of horizontal and vertically positioned screw augers, which are housed in steel piping. When the feedstock enters the top of the unit, a rotation dispersion disk assists with the even distribution of the feedstock inside the unit. Degraded material is taken out from beneath the unit via a hydraulically operated vibratory gate. The residence time is predefined.

This composting unit is not provided with mechanical aeration, and thus aeration and temperature control is not possible. The temperatures experienced in the top of the vessel are between 68° C and 85° C, which exceeds the optimum temperature for composting (MacGregor et al, 1981). A larger temperature gradient exists in the unit, with coolest zone (40° C – 55° C) exiting the bottom of the unit. This temperature gradient exists, because the hot process gas is more buoyant than the cool process gas, hence significant heat accumulation in the upper zone.

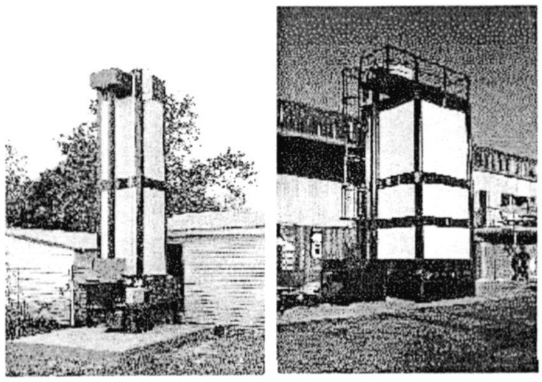


Figure 3.7: New Zealand Vertical Unit

Under the thermophilic conditions at the top of the vessel, microbial activity in this area is severely compromised resulting a slow decomposition (Miller, 1993). According to manufacturers, numbers of different sizes have been developed. With a four-week cycle, 25m^3 unit has a maximum capacity of 460 kg/d. Major advantages associated with this system are continuous flow mode reducing the equipment and labor required in batch processes.

The higher temperatures in the top inactivate the pathogen of incoming materials. These systems are modular hence can be installed, as the capacity needs. Electricity required is low due to passive aeration.

b. Japanese Vertical Unit

In Japanese Vertical Unit, an internal aeration and mixing system is present (see figure 3.8). An aeration fan installed on the top of the unit delivers air to a hollow central pipe in the unit. The hollow central pipe feeds a number of horizontally mounted aeration tubes, which deliver air to the composting mass. The horizontally mounted aeration tubes, through the rotation of the central aeration pipe, which is run by an electrical motor, constantly mixes the entire composting mass.

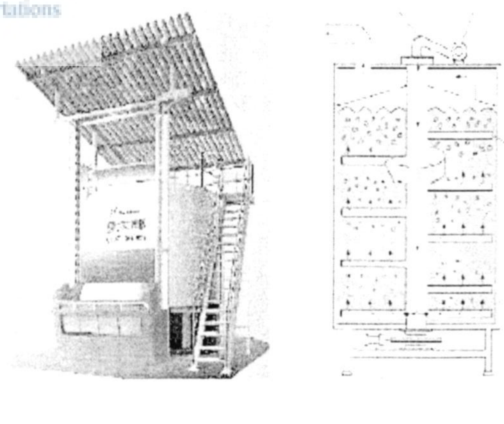


Figure 3.8: Japanese Vertical Unit

Air that is forced through the composting mass is ducted away from the top of the unit and is discharged into a biofilter for odor control. The decomposed material is taken out from a front door on the composting unit.

c. Inclined Step Grate Compost Vessel

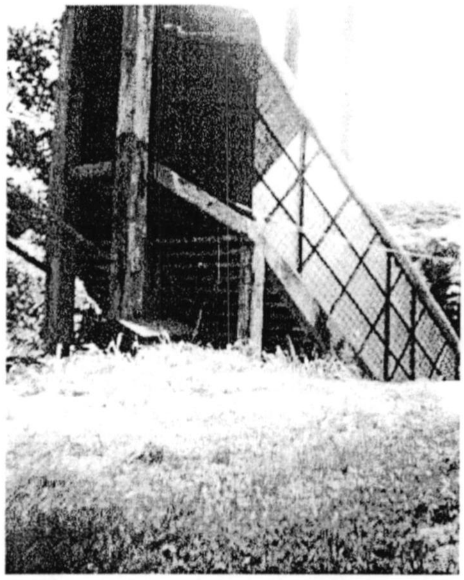


Figure 3.9: Inclined Step-Grate Unit

Composting is occurred in the vertical aeration unit in which aeration is achieved through the chimney-assisted flow under natural convection of a black body (see figure 3.9). Substrate is fed from the top of the unit and the matrix is settled on the concrete step-grate. With the decomposition and feeding from the top, the materials are flown down by their self-gravity. From the lower end the decomposed materials are taken out. No extensive pre sorting is done and the degraded materials are screened before send to the curing pads. Basnayake et al (1998) claimed that the existing large-scale urban waste compost making units involve elaborate and often unhygienic methods for separating the non-biodegradable fraction prior to aerobic treatment of the material. Hence, it has been developed this technology. The design has been done by considering the waste composition and the way of usage of small plastic bags in Sri Lanka (Basnayake et al, 1998).

Bertoldi et al, 1990 pointed out that, in continuous vertical systems, which may contain one single mass up to 9 m high, the process is extremely difficult to control the uniform oxygen distribution through the mass. Even air is blown through the beneath, air per unit surface area should be proportional to the height criterion does not match. Further, vertical systems are difficult to manage, if the discharging mechanisms breakdown or need maintenance and repair. Manual discharge of 1000 – 2000 cubic meters reactors are rather difficult. However, Basnayake et al (1998) stated, though the Tower Silos are becoming more popular and growing a demand for such units among the developed countries, the installation and operational cost is very high. Further, they claimed that the compaction in bottom of these units are overcome using very large augers and thereby increase the aeration in the lower part of the reactors.

3.3.2 Horizontal Reactors

Material inside the reactors could be static or periodically turned and pile should not exceed the 3 m of height. These reactors are normally blown through a plenum under the mass with greater process control.

The compostable material is loaded into the container after it is shredded and mixed with bulking agent (if necessary). Once full, the operator closes the container, attaches the aeration lines and inserts the temperature probes. The PC based control system regulates sterilization during 10 to 24 days of active composting. Then, Container is picked up by a roll-off truck and dumped at the product storage area. The compost may be screened in order to recover bulking agent and improve the compost product (http://www.recycle.net/bioresource/gmt1.html). The figure 3.10 and figure 3.11 show, how containerized composting system is handled.

Figure 3.10: Containerized composting unit

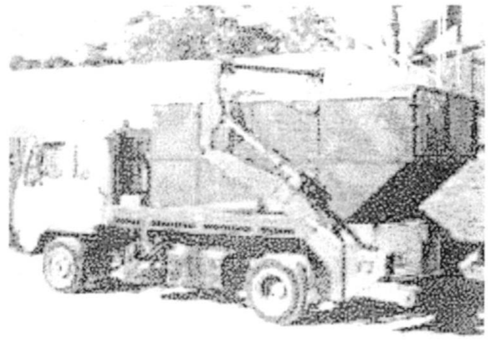


Figure 3.11: Moving by a skip truck

In closed systems, horizontal reactors seem to guarantee better control over pathogens than vertical continuous systems due to the fact that masses 3 m high are difficult to control during the composting process. In particular, oxygenation of the mass is not homogeneous, giving anaerobic zones with lower temperature (de Bertoldi et al 1990).

3.3.3 Rotating drum Reactors.

Schulze (1962) claimed the rotating drum appeared to offer a high degree of control over the process parameters. However, Schulze stated that small rotating drums lead to heat losses connected with the daily removal and addition of composting materials in which heat losses were probably greater than the heat produced in the unit.

Figure 3.12: Rotating Drum in farm scale

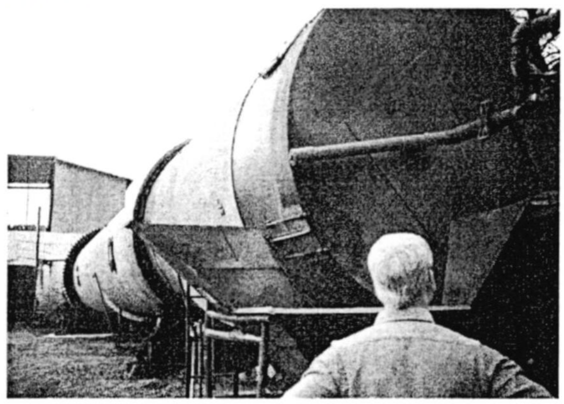


Figure 3.13: Rotating Drum in large scale

Suler & Finstein (1977) stated that composting processes of the intermittently charged type, employing well-designed digester structures, eliminate the initial mesophilic stage and operate continuously in the thermophilic range. Further Suler & Finstein (1977) claimed, compared to batch composting, the continuous type is more amendable to process control, which is especially advantageous in the treatment of solid waste of an obnoxious odor.

The Eweson digester is a co-composting process that combines the MSW and liquid sewage sludge to produce compost. The drum is 11 feet in diameter and 120 feet long. This reactor has been divided into three chambers; the first is 49 feet long and has a loaded capacity at a depth of 11 feet of 4650 ft^3. The second chamber is 36 feet long and has loaded capacity of 3420 ft^3. The third chamber is 35 feet long with a capacity of 3325 ft^3. The first chamber is the receiving one and it is loaded by a hydraulic ram and it has been designed to handle about 35 tons of liquid sewage sludge. Residence time of first chamber is one day. Loading could occur over 4 to 8 hours and transfer to the second chamber depending on the operating strategy. The digester was designed for three-day process and having residence time one day in each chamber. The first two chambers are externally insulated to minimize the conduction and radiation heat losses. The longitudinal flights inside the drum assist in the mixing of the contents and accumulate the organic matter on the walls between flights, which provides the additional insulation. Also it provides a rubbing surface that diminishes wear on the drum by abrasive materials. The air supply for the prototype is 300 ft^3 per minute provided by a semi centrifugal fan. The airflow was in counter direction to the material flow. The rotation of the drum is one rpm. It has observed the slower rates of rotation elevate the drum temperature (Singley).

A horizontal flow composting process such as the **Bedminster** co-composting process is suitable for composting MSW and sewage sludge together (See figure 3.13). The digesters can handle up to 60 tons of MSW and 30 tons of sludge per day. After sorting and mixing, the feedstock is transferred to the digesters i.e. rotating drums divided into three compartments and pitched at a slight angle to allow the waste to travel along the system. Each compartment holds 90 tons of waste a day therefore; when full each digester is composting 270 tons at any one time, in a continuous batch system. The waste travels through with the help of small scoops, and is removed daily from the end of the tunnel. Each time a batch is removed the one behind it is transferred to the following compartment. The process operates at between 65° C -71° C for two days, which ensures that all pathogens are inactivated. Air is introduced to the process by pumping from the end of the digesters and so flows in the opposite direction to the waste.

From an environmental or regulatory standpoint, in-vessel composting minimizes odor generation, reduces odor emissions, and meets pathogen reduction requirements. The process control system allows for record keeping which meets regulatory compliance requirements. Using a personal computer, a report can be produced for each batch of compost. From an operator standpoint, the computer control system measures both airflow and temperature parameters so that the operator can monitor and control the composting process. The modular design allows the operator to experiment and evaluate small batches of different feedstock mixes for handling larger volumes of materials. In general, an in-vessel composting system can be easy to operate and maintain. It can also be expanded to accommodate increases in compostable materials collection. (http://www.environmentalindustry.com/swt/media/default.asp)

3.4 Review of composting applications.

Higgins (1983) proposed a classification for controlling the use of compost in five classes. Those are general public (Class 1 users), food growers (Class 2 users), nonfood growers (Class 3 users), private institutions (Class 4 users) and public institutions (Class 5 users). Defining the quality standards for the compost made out of municipal solid waste is far from simple due to heterogeneous nature of the substrate used and different technologies used in the process. However, specifications on composting, stabilization and hygienic standards are generally related to minimum values of desirable constituents and to maximum tolerable loads for unwanted ones (Bertoldi et al 1990).

Table 3.4 Ranges of Users, Form Distribution, and Final User Group

Ranges of Users	Form Distribution	Final User Group
Private Residential		
Food applications	Bulk or bagged	1
Non food applications	Bulk or bagged	1
Private Food		
Grains for food & feed	Bulk for soil conditioning and nutrients.	1
Vegetables for food & feed	Bulk for soil conditioning and nutrients.	1,3
Forages for feed	Bulk for soil conditioning and nutrients.	2
Fruit trees	Bulk for soil conditioning and nutrients.	20
Private Nonfood		
Forage for horses	Bulk for topdressing and fertilizing.	3
Greenhouses	Bulk to greenhouse for own use.	3
Nurseries	Bulk for mulching.	3
Garden Centers	Bagged for retail sales.	1,3
Golf courses	Bulk for topdressing and fertilizing.	4
Landscape contactors	Bulks for beds and lawns.	1,3
Turf grass farmers	Bulk for soil conditioning and beds.	4
Industrial parks and ground	Bulks for beds and lawns.	4
Cemeteries	Bulks for lawns.	4
Public Agencies		
Public parks	Bulk for soil conditioning & topdressing.	5
Play grounds	Bulk for soil conditioning & topdressing.	5
Roadsides and medians	Bulk for cover establishments.	5
Military installations	Bulk for soil conditioning on grounds.	5
Public grounds	Bulk or bagged for lawns and beds.	5
Land Reclamation		
Landfill Cover	Bulk for intermediate and final cover.	4,5
Stripped mined lands	Bulk for vegetation establishment.	4
Sand and Gravel pits	Bulk for vegetation establishment.	4
Landfill		
Compost disposal	Bulk disposal.	4

General public (Class 1 users), Food growers (Class 2 users), Nonfood growers (Class 3 users), Private institutions (Class 4 users) and Public institutions (Class 5 users).

In order to use compost as a soil conditioner in agriculture, it should consist physical, chemical and biological stability, non-phytotoxicity and balance among mineral elements in the compost. Certain compounds absorbed onto the compost tend to be degraded microbially in place. Hogan & Finstein (1991) showed the compost as a scrubber material combines the features of absorbent; treatment medium and it would ultimately be incorporated into the plant growth system, resource regeneration. Finstein et al (1985) indicated that compost can be used as a partial landfill cover and it is novel use is the waste derived, low-grade solid fuel. Compost can help control plant disease and reduce crop losses. Disease control with compost has been attributed to four possible mechanisms: (i) successful competition for nutrients by beneficial microorganisms; (ii) antibiotic production by beneficial microorganisms; (iii) successful predation against pathogens by beneficial microorganisms; and (iv) activation of disease-resistant genes in plants by composts. (EPA530-F-97-044, 1997).

3.5 Compost as a resource for soil enhancement and limitations.

Finstein et al (1985) showed the application to disturbed land for reclamation purposes in order to enhance it greatly. Zorpas et al (1999) showed that compost consists of major plant nutrients such as N, P, K, micronutrients such as Cu, Fe, Zn and organic matter for improving the physical properties in order to have a better soil aeration and water holding capacity. Further Zorpas et al pointed the major limitation of land application of sewage sludge compost is the potential high metal contents and hence the possibility of bioaccumulation. Heavy metals in small concentrations consists of valuable trace elements for the plant development, and in higher concentrations, they became phytotoxic and toxic agents for human health (Zorpas et al, 1999). Higgins (1983) claimed that Cation Exchange Capacity (CEC) and pH are important factors in regulating the release of heavy metal solubilization and mobilization; soil pH should be maintained at 6.5 or higher. Properly prepared cured compost has a near neutral pH and heavy metal availability should be retarded in the soil, if the pH is maintained.

However, Hogan & Finstein (1991) argued inadequately treated compost, may harm plants through the generation of fermentation products such as Acetic acids, or the immobilization of Nitrogen owing to an excessive wide ratio of C/N.

3.6 Further Research Needs

It was proposed by Finstein and Hogan (1993) that the researches are needed in use of higher "low" fan settings during the earliest composting phase to avoid anaerobic conditions; investigating the effects of different aeration schemes on odor production; and further investigating the effect of oxygen, temperature and aeration on composting system behavior via heat output as an indicator of the decomposition rate and nitrification as an end-point indicator. Further work is required to determine the best in-vessel residence time depending on the process configuration and the substrate used.

Water is a critical physical factor in composting ecosystems. And, it is important in enhancing substrate availability and colonization of the substrate, and in gas diffusion, yet water physics in composting systems has been little studied (Macauley et al, 1990). Blanc et al (1999) pointed out that further research is required for better understanding how bacterial populations, not only aerobic thermophiles, but also thermoresistant mesophiles and anaerobes, vary as a function of time and space in a compost matrix. Beffa et al (1998) recommended carrying out the fundamental research on the detection of medically important fungi in biowaste and compost. Further, they argued the positive epidemiological evidence is the best argument to conclude from potential hazard to actual risk. Emphasis must be placed on possible biases, which may lead to some underestimation of long-term effect.

Composting is a very complex biological process in which more interdisciplinary researches are needed to effectively control the process parameters (aeration cycles, turning frequency, substrate formulation, temperature regulation etc), indispensable for an optimal degradation, hygienisation and maturation.

Chapter Four

Composting System Design and Utilization

This chapter identifies the basic parameters important in design and utilization of a composting system. Based on these factors the subsequent design is carried out. Factors considered in selecting the technology are shown in figure 4.1

4.1 Selection of the composting technology

When selecting an appropriate technology for composting solid waste, it is important to consider the following factors. Most projects have been failed or operating under poor conditions due to the negligence of implementers to consider the following factors or their combinations. Thus the design of the present system had followed due consideration of the following;

4.1.1 Available space

Technology can be selected according to the space available. If the plant to be setup in a remote area and more space is available, low rate technology (space consuming) such as windrows can be selected. However, if the available space is limited, then high rate technology such as in-vessel technologies are more suitable. It is interesting to note that usually where space is limited much waste is also generated as in an urban setting.

4.1.2 Characteristics of waste

If the waste substrates are odorous and wet, in-vessel technologies are more suitable. Specially, co-composting of sewage sludge, slaughterhouse waste with other materials can easily be done by avoiding the odor, which may cause public opposition. Composting of yard trimmings, tree cuttings can be done using the open systems, if enough space is available.

4.1.3 Degree of process control

When process control needs are more extensive, it is much easier to use in-vessel composting than the open systems. Since, confined systems have a higher degree of control over the manipulative parameters. However, the design needs to consider the suitable sensor set up which will tolerate the extreme conditions inside the reactor. Sensitivity will reduce with time due to surface property changes and would tend to produce incorrect values for the specific parameters such as temperature, moisture content etc. Proper understandings of these are necessary for control to be effectively carried out.

4.1.4 Desired end product quality

Consistent product output can be met easily using in-vessel technologies. However, cost of production is high due to high energy and being mechanical operated systems. These systems have greater process control ability than the open systems while ensuring the closer monitoring of critical parameters such as temperature, aeration (O_2 content) and moisture content.

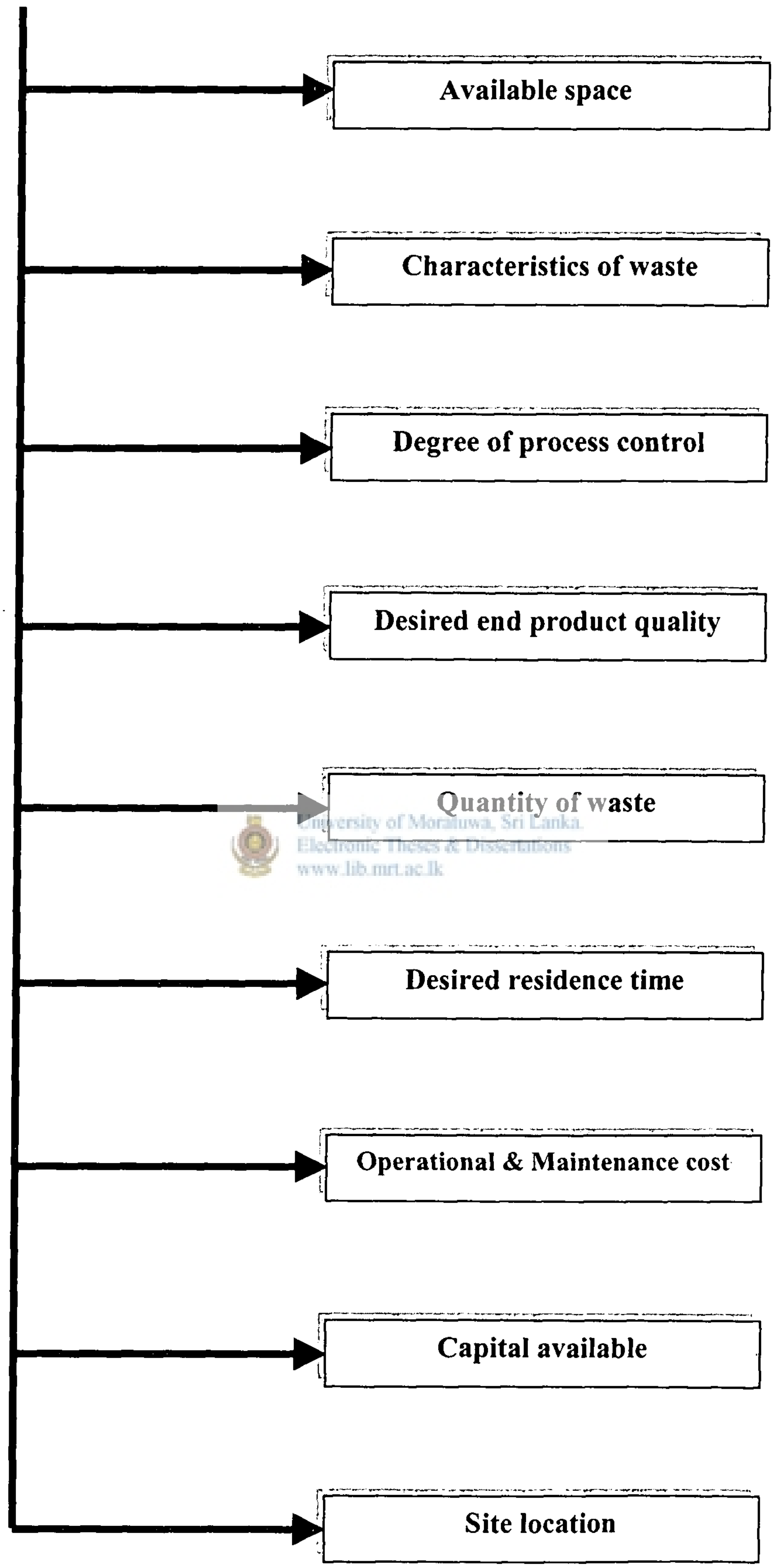


Figure 4.1: Selection of the composting technology

4.1.5 Quantity of waste

Available waste quantity also can dictate the type of technology to be employed in order to treat the waste in a given area. However, this has to be considered with other factors such as available space, site location, capital available and desired product quality. When a larger quantity of waste has to be treated in an urban area with limited space, it is appropriate to use in-vessel technology than the space consuming open systems. On the other hand, when a small waste quantity is available in confined areas such as farms, one could utilize a mobile in-vessel composting system according requirement of shifting the place time to time. Even in rural urban areas where space is limited with lesser quantity of waste mobile units are possible. However, if the available space and site location are not constraints, then open systems can be selected with lesser capital and operational costs.

4.1.6 Desired residence time

Residence time is important, when composting as a waste treatment technology. The priority requirement in waste management is, how quickly a given waste quantity can be converted into compost in an environmentally friendly manner. In order to meet this requirement, it needs to employ a method, which has a greater process control with appropriate residence time.

4.1.7 Operational & Maintenance cost

Operational and Maintenance costs are also important factors in the long run in composting operation. This affects the cost of production and hence the market price of the product. In order to be competitive in the market, the price of compost should be as low as possible unless otherwise government agencies take a policy decision for promoting composting as a waste remedial technology. Therefore, the type of technology is crucial in selecting the best practice of composting for a given area. Though in-vessel technology gives a better process control while ensuring the utilization of less space, consistent product quality and better odour control, higher operational cost is inevitable. However, open systems such as windrows have low operational and maintenance cost with respect to in-vessel technologies at the expense of space and rigorous operator skill involvement in the process control.

4.1.8 Capital available

Capital available also decides the level of technology that can be afforded by a given party when selecting composting as a waste management method. High capital-intensive processes have received less attention than the composting systems such as windrows, which requires less capital. However, it should be noted that the high capital-intensive processes like in-vessel technologies have a better process control ability than low-level technologies. It is also important that a wrong technology type is not selected simply because of low-level capital available and had to be spent.

4.1.9 Site location

Composting is an environmental and a social sensitive technology. If the process is not properly managed, leachate and bad odour with longer decomposition periods can cause significant problems. On the other hand, bad odour and leachate create public opposition due to smell and possible ground water contamination from treatment sites. Therefore the setting up of composting plants close to urban areas is a complex issue, unless suitable precautions are taken to avoid the bad odour and ground water contamination. It is a common acceptance that out of sight is out of mind with respect to solid waste. This analogy can be applied even in composting by covering the area using a suitable green belt or using the in-vessel technology as appropriate. Specially, in areas where space is lacking and in more densely populated areas with high waste quantities, the in-vessel technologies are favorable over the open systems.

4.2 Feedstock Characterization and Preparation

For the optimum decomposition, it is important to keep the nutrient conditions optimal while the other environmental factors (such as temperature, aeration, particle size etc) are kept in their respective optimum ranges. Carbon provides the energy required for the microbes while nitrogen is an essential component for the protein synthesize in microbial cells. Haugh (1993) states a C/ N ratio of 30 – 35 to optimize the compost processing, since lower C/N ratio indicates the potential loss of nitrogen through ammonia volatization. Berube and Beausejour (2001) propose the C/N ratio could vary between 20:1 to 25:1, which could be volumetrically approximated through combination of four parts of brown, dry, carboneous matter for each part of green fresh material. Further Berube et al (2001) quotes from an experiment in Netherlands by Roosmalen and Langgerijt, 1:1 ratio of residual and yard trimmings on weight basis to have been quite successful.

The nitrogen content is experimentally found using the Kjeldhal method, while the carbon content can be approximated with a 2 – 10 % error using the following equation (Diaz et al, 1993).

$$\% C = (100 - \% ash) / 1.8$$

The values of approximate nitrogen content and C/N ratio for various waste materials that appear in Table 4.2 could be assisted to elaborate a mixture that contains suitable C/N ratio.

Table 4.2: Approximate nitrogen content and C/N ratio in various waste materials

Material	Nitrogen % dry weight	C/N ratio
Night soil	5.5 – 6.5	6 – 10
Urine	15 – 18	0.8
Blood	10 –14	3.0
Cow dung	1.7	18
Poultry dung	6.3	15
Raw sewage sludge	4 – 11	11
Activated sludge	5	6
Grass clippings	3 – 6	12 – 15
Nonlegume vegetable waste	2.5 – 4	11 – 12
Mixed grass	2.4	19
Sawdust	0.1	200 - 500

The presence of lignin affects the degradability of a given substrate, since the non-degradable organic barrier limits the microbial access to the surface area of cellulose fibrils for further decomposition. Food wastes, consisting post-consumer food residues, discarded combustibles and yard trimmings provide an easily accessible energy source and modest amount of nitrogen for enhanced microbial activity. Thus, the biodegradation of yard trimmings accelerates when they are combined with food waste in composting process (Diaz et al, 1993).

$$\text{Moisture content} = \frac{\text{Wet weight} - \text{Dry weight (24hrs at } 105°\text{ C)}}{\text{Wet weight}} \quad (1)$$

Knowing the moisture content, Carbon content and Nitrogen content, a suitable feedstock formula can be developed as follows.

1 kg of sample i:

Water content	=	Moisture content x 1 kg	=	$M_{w,i}$ kg
Dry matter	=	$(1 - M_{w,i})$ kg		
Nitrogen content	=	Dry matter x (% N)	=	$M_{N,i}$ kg
Carbon content	=	(100 - % ash) / 1.8	=	$M_{C,i}$ kg or
Available C/N ratio	=	$(M_{C,i} / M_{N,i})$		

Say, it is needed to find the dry weight (M_d) of bulking agent to be added for the above constituent i,

$$C/N = 30 = \frac{M_{C,i} + (M_d) \times M_{C,b}}{M_{N,i} + (M_d) \times M_{N,b}} \quad (2)$$

Hence, by knowing the $M_{C,i}$, $M_{N,i}$, $M_{N,b}$ and $M_{N,b}$ from the table 4.2, it can be calculated the M_d, which should be added to every 1 kg of constituent i.

4.3 Basic design of the composting system

Although the composting process seems to be quite easy to understand, the actual design process needs careful planning in each step. This relates from raw material storage to finished product and then to marketing. Important process variables that must be considered in the design and operation of composting facilities include particle size, particle size distribution of substrate, seeding and mixing requirements, the required mixing/turning schedule, total oxygen requirement (aeration), moisture content, temperature and temperature control, C/N ratio of the substrate, pH, degree of decomposition, respiratory quotient (RQ) and control of pathogens.

4.3.1 Raw Material storage

The whole process starts by collecting the suitable feedstock. According to the properties of the materials, storage should be planned. Usually, a primary material is first selected such as yard trimmings, food residues, market waste and animal manure etc. These are stored in a place in which additional moisture will not get in. Therefore, it is better to store raw materials in a shed with a pad than on bare ground. This eliminates the bad odor as well as leachate percolation to the ground. Bulking agents like sawdust, woodchips and straw can be stockpiled in outdoors without a cover.

However the degradation would occur, if moisture gets mixed. But this could be slow decomposition due to the fact that high carbon and low nitrogen conditions. However, primary materials should not be stored for longer periods, which will be ultimately subjected to non-uniform degradation even with anaerobic conditions.

4.3.2 Size reduction

If the particle size is more than 5 - 7 cm, it is required to do the size reduction in order to increase the surface area. A hammer mill or a shear shredder can be employed according to available substrate. Especially, yard trimmings and tree cuttings have to be size reduced. Capacity of the mill or shredder can be found according to the daily plant feed. Even newspapers, cardboards will require the size reduction for increasing the degradability. However, if rotating drum or mixing type reactor is employed for the composting process, moisture and tumbling effect reduces the particle size of those materials and hence eliminate the need for shredding.

4.3.3 Mixing

Proper mixing of various feedstocks accelerates the decomposition by achieving the optimum C/N ratio, moisture content and providing the porosity. Therefore, once the basic parameters like moisture content, wet weight, C content and N content of different substrates are established, one can calculate the weight of the bulking agent or any other additive required for the optimum decomposition using equation (2). Mixing can be accomplished either by a turner or built into the design itself. Screw auger, baffles or self-gravity falling (rotating drum, inclined step grate etc) will mix materials in in-vessel composting.

4.3.4 Reactor design and composting

The reactor design can range from open systems to closed (In-vessel) systems depending on the requirement. The type of reactor can be decided as discusses in section 4.1 by considering all the factors discussed.

4.3.5 Residence time

Schulze (1962) showed that there is a considerable loss of volatile matter during the passage through the drum, residence time should not be computed on the basis of dry weight or volatile matter. Ash data appear to be better suited for this purpose, because it can be assumed that the aerobic decomposition process will not change the fixed matter. Therefore, the residence time can then be estimated by the ratio of the weight of ash from the material in the drum to the daily input of ash from the raw feed.

$$\%\text{ Reduction in dry weight} = \frac{AD - AR \times 100}{AD}$$

$$\%\text{ Reduction in Volatile matter} = \frac{\%\text{ reduction dry weight} \times 100}{100 - AR}$$

$$\%\text{ Reduction in volatile matter} = \frac{(AD - AR) \times 100}{AD\,(100 - AR)}$$

AD – % ash in decomposed (out going material)

AR - % ash in raw (incoming) material

Note: It is obvious that the material removed from the drum consisted of mixture of particles with residence times ranging from a minimum of 1 day (in the case of daily feeding) to a maximum of weeks or months, depending upon the length of time the drum had been in continuous operation.

$$\text{Residence Time (r)} = \frac{\text{Active volume or weight of the material in the rector (V)}}{\text{Rate of flow of the material (f)}}$$

4.3.6 Curing

After the active composting period, further period of curing is required for the completion of composting. Rynk et al (1992) suggested that at least a month is needed to finish the process and allow the compost to develop the desired characteristics for its intended use. Curing is done in a separate area so that active composting can be used for new feedstock. However, curing can be done in the active composting area too. Proper aeration conditions are important even at the curing stage, since compost undergoes slow decomposition during curing. In order to decrease the curing period, forced aerated system can be applied, but need to compromise between the cost and the time, which is more important. Curing piles should be small enough to have adequate aeration. The maximum pile height often suggested is 2 m and the width could be 5 to 7 m (Rynk et al, 1992). Further, it can be closely positioned the curing pile than the active composting stage.

It is required to construct proper drainage in order to channel the surface runoff from the curing pads. Anaerobic conditions can also arise from excessive moisture or water, which accumulates underneath of the pile. Curing stage does not generate much heat for excess water to vaporize. Therefore, drainage in the curing area has to be well designed to avoid any accumulation of excess moisture. An effective method to avoid the wet or anaerobic conditions is to remix and spread the compost in curing piles in an open area. This helps to oxygenate the piles well and allows anaerobic compounds to be decomposed aerobically or evaporate (Rynk et al, 1992).

4.3.7 Sieving and packing.

Sieving is important to remove the unwanted materials from the compost. The larger particles, which have not been properly decomposed, are removed. According to the different applications, the required particle size will be varied. In order to meet this quality criterion sieving can effectively be used. It should ensure that the product does not contain any glass pieces, metals etc before being sent to the market.

Packing can be done according to market requirements. It is wise to put a label including the start date of manufacturing, sample analysis by a certified body, type of raw materials used, date of packing, manufactures details and quantity of product etc for the benefit of the consumer.

Table 4.2 Important design considerations for aerobic composting process.

No.	Design Parameter	Comments
01	Particle Size	For optimum results the size of solid wastes should be between 25 and 75 mm.
02	C/N ratio	Between 25 and 50 optimum; At lower ratios N_2 is loosing as NH_3. Biological activities are also impeded at lower ratio. At higher ratios N_2 may be the limiting factor.
03	Blending & seeding	Composting time can be reduced by seeding with old compost or with partially decomposed materials.
04	Moisture content	Moisture content should be in the range of 50 to 60 percent.
05	Mixing / turning	To prevent drying, caking and air channeling, material in the process of being composted should be mixed or turned on regular basis.
06	Temperature	For the best results, temperature should be maintained between 50 C to 55 C for the first few days and 55 to 60 C for the remainder of the active composting period. If the temperature goes beyond 66 C, the biological activity is reduced greatly.
07	Control of pathogen	If properly controlled, it is possible to eliminate this problem during the composting period. The temperature must maintain between 60 and 70 for 24 hours in order to meet this.
08	Air requirement	The theoretical oxygen demand can be calculated. Air with at least 50 % of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results.
10	pH control	To achieve an optimum aerobic decomposition, pH should remain at 7 to 7.5 range. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above about 8.5.
11	Degree of decomposition	This can be estimated by measuring the final drop of the temperature, degree of self heating capacity, amount of decomposable and resistant organic matter in the composted material, oxygen uptake, growth of the fungus *Chaetomium gracillis* etc.

4.4 Process Control

Rational composting process control involves the interrelated factors of heat output, temperature, ventilation and water removal / addition (MacGregor et al, 1981). However, as it was discussed in the previous chapter, the process control has been limited to either temperature and aeration control or open loop water addition in most of the systems. This does not provide the optimum conditions for the microbes in order to degrade materials rapidly. Therefore, it is important to implement an integrated control strategy rather than the temperature and / or aeration control strategy alone. For example, as it was shown by the improved Rutgers Strategy, a combination of temperature and oxygen feedback has shown success. If the above control strategy can be coupled with the feedback moisture content in the reactor, the retardation of microbial activities due to lack of moisture during the latter part of the process can be avoided. (See chapter 5, section 5.1.10) Then it can maintain the optimum temperature and aeration conditions while having the required moisture content inside the reactor throughout the process. This would enhance the degradation considerably without subjecting to the moisture lack conditions in the latter part of the composting.

4.5 Typical compost analysis from Sri Lankan practices

Compost samples were obtained from various composting sites and shops were subjected to analysis. The analyses were conducted at Horticulture Research and Development Institution of Sri Lanka, according to established techniques adopted for testing of fertilizers. Sri Lanka at present does not have any standards on compost. It was analyzed the compost samples to quantify the amount of heavy metal using atomic absorption photo spectrometer (GBC 932, Australia).

Chapter Five

BIOCOM-MSW System

This chapter describes the BIOCOM-MSW system, which was designed as a possible composting system to handle municipal solid waste. The selection of the in-vessel composting system was based on the reasoning outlined in the earlier chapter.

Rotating drum systems rely on a tumbling action to continuously mix the feedstock materials. The drums typically are long cylinders, approximately 3 m in diameter, which are rotated slowly, usually 1-2 revolutions per minute. Oxygen is forced into the drums through nozzles from exterior air pumping systems. The tumbling of the materials allows oxygen to be maintained at high and relatively uniform levels throughout the drum. The promotional literature for rotating drums indicates that composting materials must be retained in the drums for only 1 to 6 days depending on the manufacturers specifications. Complete stabilization of the composting material is not possible within this timeframe, however, and further curing is necessary (CRS, 1989).

5.1 Principles of the system design

Basic design parameters were taken by considering the design of Trommels used in screening applications of size reduction circuits (Perry, 1995). Trommel design is based on several parameters such as diameter, length, rotational speed, angle of inclination & feed rate. However, it is noted that the most of the rotating drum systems operate continuously and hence the energy consumption is higher with respect to the other in-vessel composting systems. In addition to above, following factors were considered with regard to mechanical design of the reactor.

1. Thermal insulation in order to avoid heat loss from the matrix.
2. Uniform aeration throughout the matrix.
3. Sensor setup (Temperature & moisture content).
4. Material input / output.
5. Reactor supporting structure.
6. Corrosion resistance.
7. Power required for rotating.
8. Supporting structure.
9. Available MS sheets in the market.
10. Minimum welding requirement.

Of these thermal insulation is the least important considering the climatic condition of Sri Lanka.

5.1.1 Reactor Sizing

Reactor sizing was done considering past experience of Schulz (1961). It was reported by Schulz that the thermal losses are high in too small reactors, hence difficult to maintain the thermophilic temperature for a reasonable time. Therefore, it was considered a moderate size reactor considering the fabrication cost and facilities available. Further, necessary precautions were taken in order to avoid developing anaerobic conditions inside the reactor by placing a spiral. This helps to break the material mix, when the matrix is subjected to rotate. Hence it avoids the formation of sticky balls as experienced by the Schulz (1961). Further design was done keeping sufficient flexibility for extension on modular basis. The following data were used in the calculation of the size of the reactor.

Density of shredded MSW (ρ_{msw}) = 600 kg/m^3
Free air space of drum = 1/3 rd of total volume
Density of Mild Steel = 7,200 kg/m^3
Sheet thickness

Gauge/in	Gauge /mm
1/8 "	3.18
1/4 "	6.35

Let's take thickness as t.
Length of the plate = L
Width of the plate = W
Volume of the plate = LWt m^3
Weight of the plate = LWt * ρ_{msw} kg

If the diameter of the drum is D, then
(22/7) x D = L
D = 7L/22

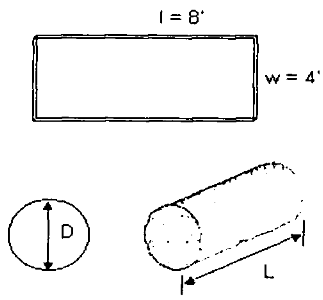


Figure 5.1 Reactor Sizing

The total weight of the drum
= Weight of the drum + Weight of the matrix

Then it was calculated the various combinations of the sizes of the reactors by varying the sheet thickness and number of sheets in order to form the cylinders. While doing this calculation, the measures were taken to minimize the number of welding ridges required and maintain the stiffness of the reactor in order to withstand the torsional effect due to rotation with the load.

Table 5.1: Reactor sizing for BIOCOM – MSW

No.	Diameter D / m	Length / m	Volume / m^3	Capacity / kg	Sheet gauge / mm	No. Of Sheets	Drum weight / kg	Total Weight / kg
1	0.78	1.2192	0.5766	230.6536	3.18	1	154.6988	416.2921
2	0.78	2.4384	1.1533	461.3072	3.18	2	222.7662	728.6266
3	0.78	3.6576	1.7299	691.9608	3.18	3	290.8337	1040.9612
4	0.78	1.2192	0.5766	230.6536	6.35	1	308.9111	601.3469
5	0.78	2.4384	1.1533	461.3072	6.35	2	444.8319	995.1055
6	0.78	3.6576	1.7299	691.9608	6.35	3	580.7528	1388.8641
7	0.78	4.8768	2.3065	922.6143	6.35	4	716.6736	1782.6227

According to above factors, the sixth option was selected for fabricating the reactor. However, the reactor length can be extended on modular basis by forming a cylinder with 4' x 8' MS sheet and fixing to the existing one through a flange as required, without changing the diameter. The figure 5.2 presents the engineering drawing of the reactor.

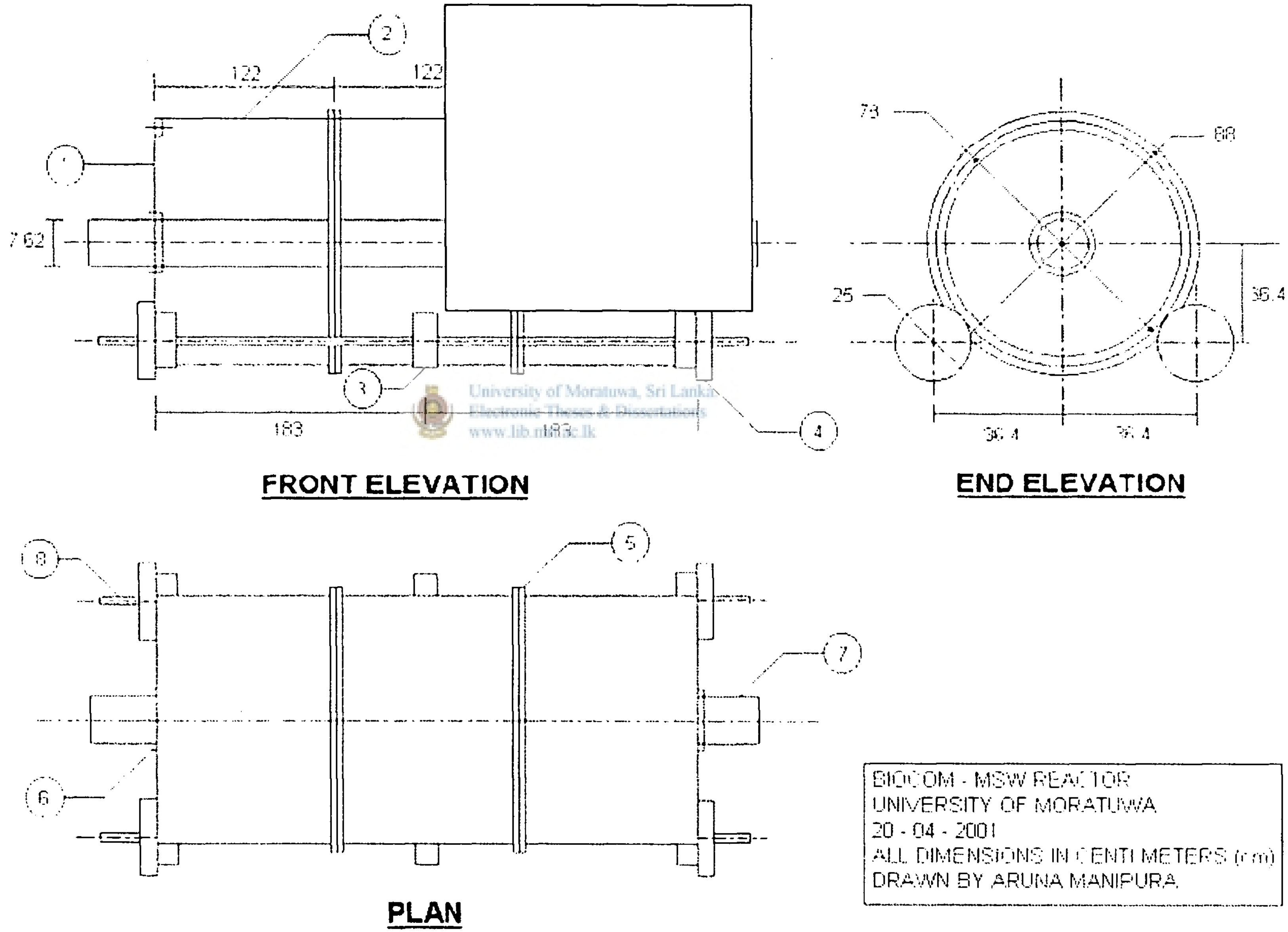


Figure 5.2: Engineering Drawing

5.1.2 Calculation of the Critical Speed

In order to occur tumbling action during rotation of the reactor, it is required to find the relevant critical speed for the selected diameter. *Rotational Speed* is a function of the *Critical Speed*: speed at which the materials centrifuge or stick to the surface of the reactor. Critical speed is given by Equation (1).

$$N_C = (1/2\pi) \times [g/r]^{1/2} \qquad (1)$$

N_C = Critical Speed (rev/S)
g = Gravitational acceleration (m/s^2) = 9.81 m/s^2
r = Trommel radius (m)

$$N_C = [1/2\pi) \times [9.81/0.39]^{1/2}$$
$$= 0.7982 \text{ rev/s}$$
$$\simeq 0.8 \text{ rev/s}$$
$$= 48 \text{ rpm}$$

5.1.3 Calculation of the Operational Speed

Ideally the rotational speed should be 50 % of the critical speed for a trommel with lifters, & up to 80 % of the critical speed for a trommel without lifters (lifters are vertical plates attached to the inside of the trommel).

Therefore, operational speed = $(1/2)*N_C$
= 0.5 x 48 rpm
= 24 rpm

Though the design was done on the basis of trommel calculations, it is needed to facilitate the microbial activities during the operation. Therefore, it was selected a 1 rpm as the rotational speed of the reactors during intermittent rotation in order to avoid affecting the microbial activities. Literature values for in-vessel composting systems are 1-2 rpm (Biocycle, 2001). This knowledge was utilized in this selection of final operational rpm.

5.1.4 Power Calculation

One of the most important parameter in designing the rotating drum is the energy consumption. In order to minimize the energy consumption, the control strategy designed to have an intermittent rotation for proper mixing and size reduction of particles. However, when the material is fed to the system, the reactor is expected to run at its full operational speed for 30 minutes in order to do the size reduction and mixing the substrate.

Total weight of the reactor	=	2,000 kg
Diameter of the reactor	=	0.78 m
Mixing rpm	=	24 rpm
Mixing duration	=	30 minutes
Intermittent rotation	=	1 rpm

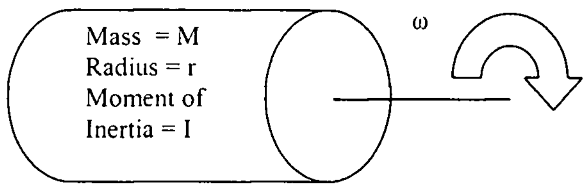


Figure 5.3: Power calculation parameters

Angular Velocity $\omega = (24/60) \times 2\pi \text{ rad/s} = 2.5123 \text{ rad/s}$

Moment of Inertia around the rotating axis

$$I = (1/2)\,Mr^2$$

Using $G = I\,(d^2\theta/dt^2)$ around axis of the drum in the direction of rotation and assuming, it is needed to rotate the system from the rest (0 rpm) to 24 rpm in 1 second.

If the required torque is τ,

Then,

$$\tau = I\,(d^2\omega/dt^2)$$
$$\tau = (1/2) \times 2000 \times (0.39)^2 \times (2.5132 - 0)/1 \text{ Nm}$$
$$\tau = (1/2) \times 2000 \times (0.39)^2 \times 2.5132 \text{ Nm}$$
$$\tau = 382.2577 \text{ Nm}$$

Required power to rotate the drum,

$$P = \omega\tau \text{ Watts}$$
$$P = 382.2577 \times 2.5132 \text{ W}$$
$$P = 960.6901 \text{ W}$$

Lets assume the power transmission efficiency from motor to drum through gearbox is 50 %. (Here driving wheels transmit the power to the drum through a groove. Therefore slips are higher than the direct gear transmission)

Therefore required motor $= 960.69 / 0.5$ W

$= 1921.38$ W

$= 1.9214$ kW

$\simeq$ <u>2 kW</u>

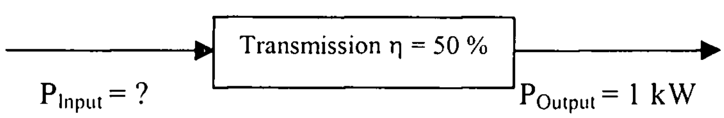


Figure 5.4: Power transmission efficiency

5.1.5 Sensor Selection

Sensors were selected by considering the process environment inside the reactor. As decomposition starts the acidic and alkaline conditions are developed over time. On the other hand, the medium is porous and need to have proper contact between the matrix and the surface of sensors in order to give correct values of each parameter. Therefore sensors were selected which are used in soil applications in order to minimize the inaccuracy due to above factors. Since the reactor is subjected rotation, the stiffness and the robustness of the sensors were also taken into account. Many sensor suppliers (National Instruments, OMEGA, Campbell) were considered before the final choice was made.

a. Temperature Probe

The Campbell 108L was selected, since it is rugged, and are accurate probes which measures air, soil, and water temperature in a variety of applications. These probes consist of a thermistor encapsulated in an epoxy-filled aluminum housing. The housing protects the thermistor allowing the probes to be buried. The 108L measures from -5° to +95°C. The specification of the 108L temperature probe is as follows (www.campbellsci.com).

Temperature measurement range	:	-5° to +95°C
Polynomial linearization accuracy range	:	Typically <±0.5°C at the -5° to +90°C
Interchangeability error	:	Typically <±0.2°C over 0° to 70°C range Increasing to ±0.3°C at 95°C
Time constant in air	:	Between 30 and 60 seconds in a wind speed of 5 m sec $^{-1}$

b. Moisture - Water Content Reflectometer (CS615)

The CS615 Water Content Reflectometer (Campbell) measures the volumetric water content of porous media using time-domain measurement methods. The reflectometer connects directly to the single-ended analog input of a Campbell Scientific, CR10 (X), datalogger. The datalogger period or frequency output is converted to volumetric water content using calibration values. The Water Content Reflectometer consists of two stainless steel rods connected to a printed circuit board. A shielded four-conductor cable is connected to the circuit board to supply power, enable the probe, and monitor the pulse output. The circuit board is encapsulated in epoxy. The probe rods can be inserted from the surface or the probe can be buried at any orientation to the surface (www.campbellsci.com).

High-speed electronic components on the circuit board are configured as a multivibrator. The output of the multivibrator is connected to the probe rods, which act as a wave-guide. When the multivibrator switches states, the transition travels the length of the rods and is reflected by the rod ends. This reflection provides feedback to switch the state of the multivibrator and initiate subsequent wave propagation on the rods. The travel time to the end of the rods and back is dependent on the dielectric constant of the material surrounding the rods. Digital circuitry scales the multivibrator output to an appropriate frequency for measurement with a datalogger. The frequency or period is used in a calibration for water content.

The CS615 response is dependent on the dielectric constant of the material surrounding the probe rods. Water is the principal contributor to the dielectric constant value, but the solid constituents such as quartz, clay and organic matter also affect the measurement. Applying the general calibrations from the operating manual provides accuracy of ± 3.0%.

5.1.6 Datalogging and Control

Campbell CR 10 (X), Datalogger / Controller is used for data logging and controlling the input / output signals. Two signals from water content reflectometer and three signals from temperature probes are fed to the CR 10 (X) and compare with the set points. According to the difference between set point and the existing values, the solenoid switches open the relevant valves for aeration and moisture spraying. In the interval of 15 minutes the data sets are logged and those could be downloaded weekly to a PC through RS-232 port in the Datalogger (www.campbellsci.com).

5.1.7 Control Strategy

The control strategy was selected by considering the past experience of Rutgers strategy, improved Rutgers strategy (Linear Temperature Feedback) and Oxygen Feedback control systems. Then, it was considered the optimization of rotation and hence, the minimum energy consumption during the operation. Rather than continuous operation adapted by the most of the rotating drum systems, the BIOCOM-MSW will follow an intermittent rotation of the system similar to simulation of turning the windrows in open systems. However, forced aeration is carried out according to the temperature increase inside the matrix (see figure 5.7 for more details).

5.1.8 Instrumentation Set up

All the sensors were fixed to the MS steel pipe which runs through the axis of the reactor. Then the pipe was fixed to the supporting structure. Sensors were placed in three sections with even distance so that it conforms a uniform representation of parameters measured. Moisture sensors were fixed just below the moisture nozzles, since that area subjected to the least moist condition. Aeration nozzles were fixed at two depths in order to ensure the proper aeration in the substrate. There are three sets of aeration nozzles as such which help to uniformly aerate along the reactor. Figure 5.5 gives more details of the instrumentation system designed for BIOCOM-MSW.

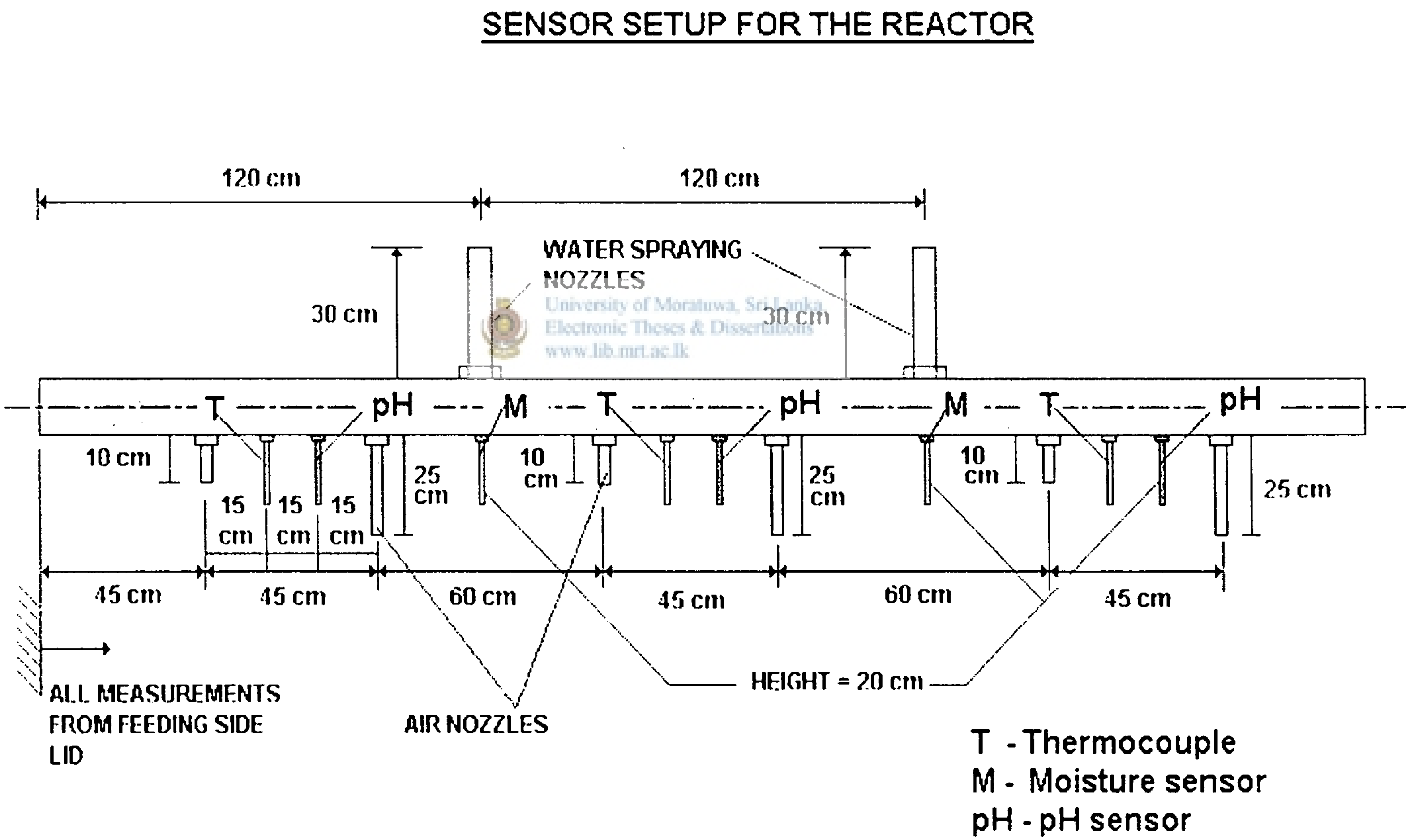


Figure 5.5: Instrumentation Set up

5.1.9 Basis for BIOCOM – MSW Control Strategy

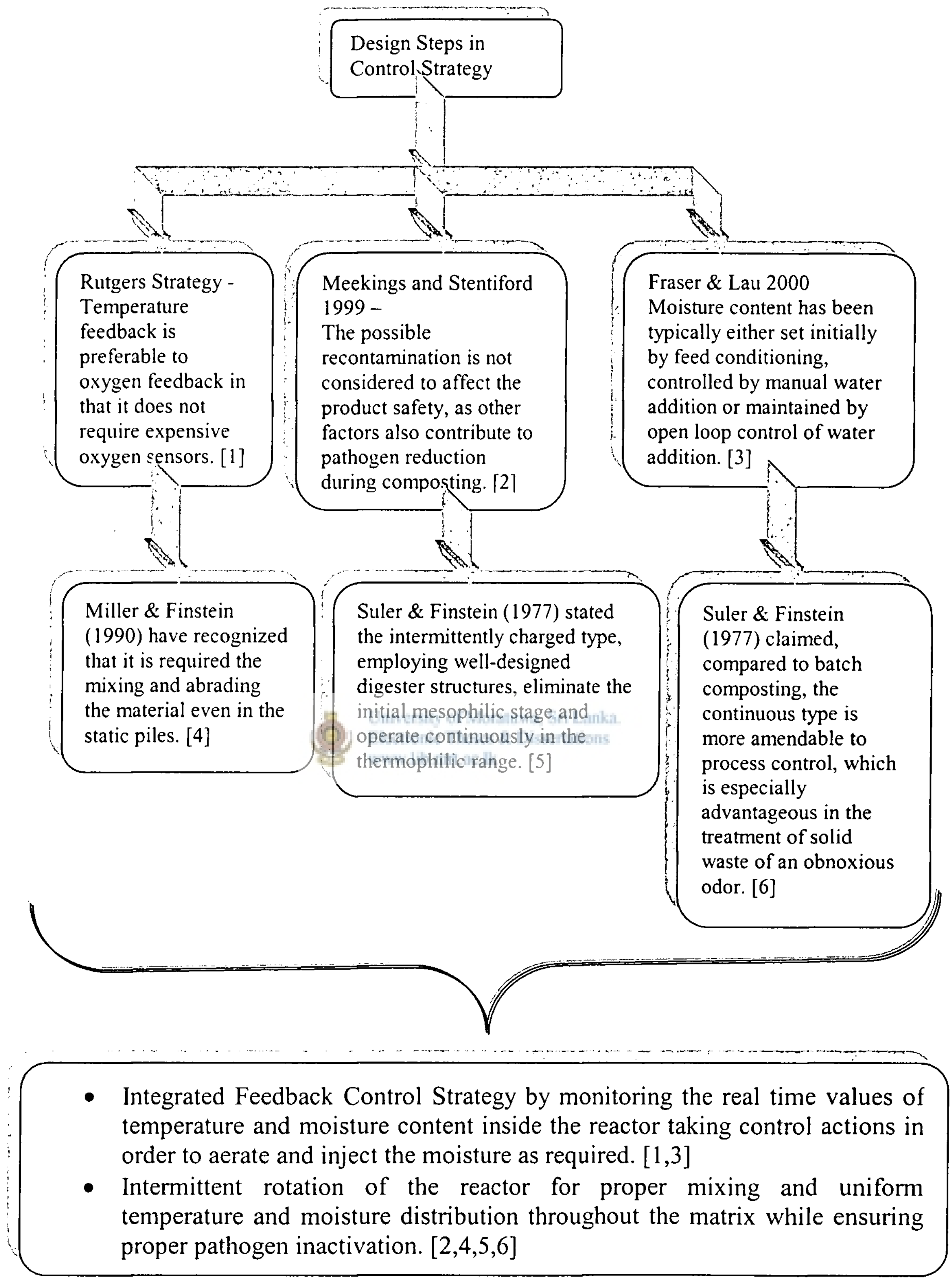


Figure 5.6: BIOCOM – MSW Control strategy formation

5.1.10 BIOCOM – MSW Control Algorithm

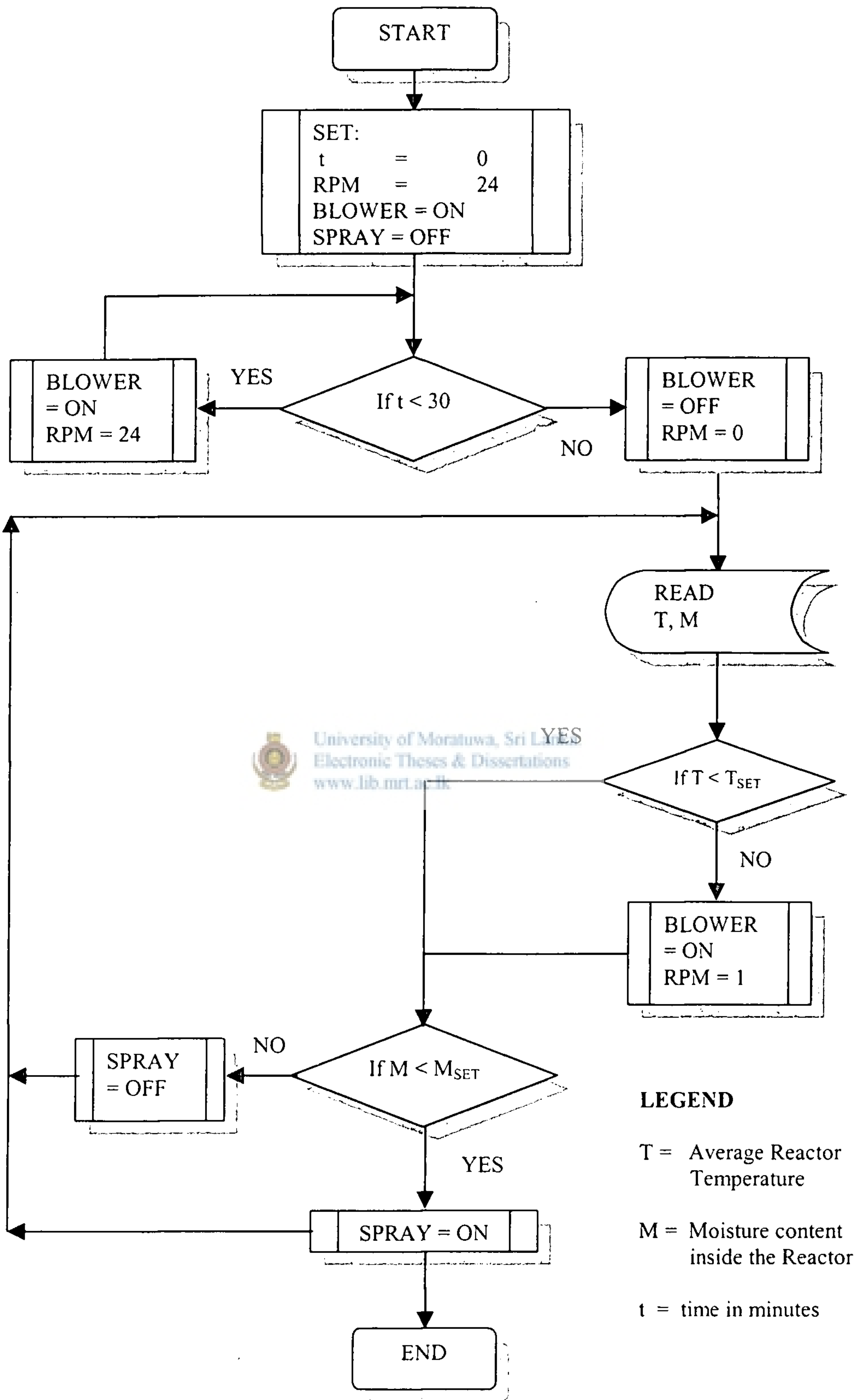


Figure 5.7: BIOCOM – MSW Control Algorithm

5.2 System characteristics

The complete BIOCOM – MSW system consists of a Shredder, Rotating Drum Reactor and Accelerated Curing unit. However shredder and accelerated curing unit were not included during the first phase of the project and it will be done during the second phase of the project work. Each unit is connected through conveyers and hence minimum worker contact with the waste is expected to be achieved.

First, incoming materials are presorted at the site and weighed. Then, feedstocks are formulated and fed to the shredder or directly send to the reactor itself. In initial stage, it has avoided the use of shredder. Therefore, it is required to do the size reduction by running the reactor at its full operational speed for 30 minutes. This time period has to be optimized according waste characteristics and moisture content. Hence, it can be enhanced the energy requirement further. It is intended to use a garden shredder with 600 kg / hr processing capacity which is available in the market.

Then the reactor is allowed to increase the temperature up to the set point of 60° C and the moisture content of 60 %. Then the temperature feedback control system takes the configuring the aeration and turning requirement in order to keep the optimum temperature and the aeration conditions inside the reactor. However, it measures the real time value of moisture condition and if the moisture content decreases below the set point, water vapor is sprayed to the system through the nozzles up to the set point. Hence, it is eliminated the moisture limiting condition that could develop within the system.

Once the material is taken out from the reactor, it is directed to the accelerated curing unit through the conveyers. In accelerated curing unit, decomposed materials are subjected to forced aeration based on the microbial heat output (Rutgers strategy) through a plenum under the curing unit. The final design layout of the BIOCOM-MSW is given in Figure 5.8.

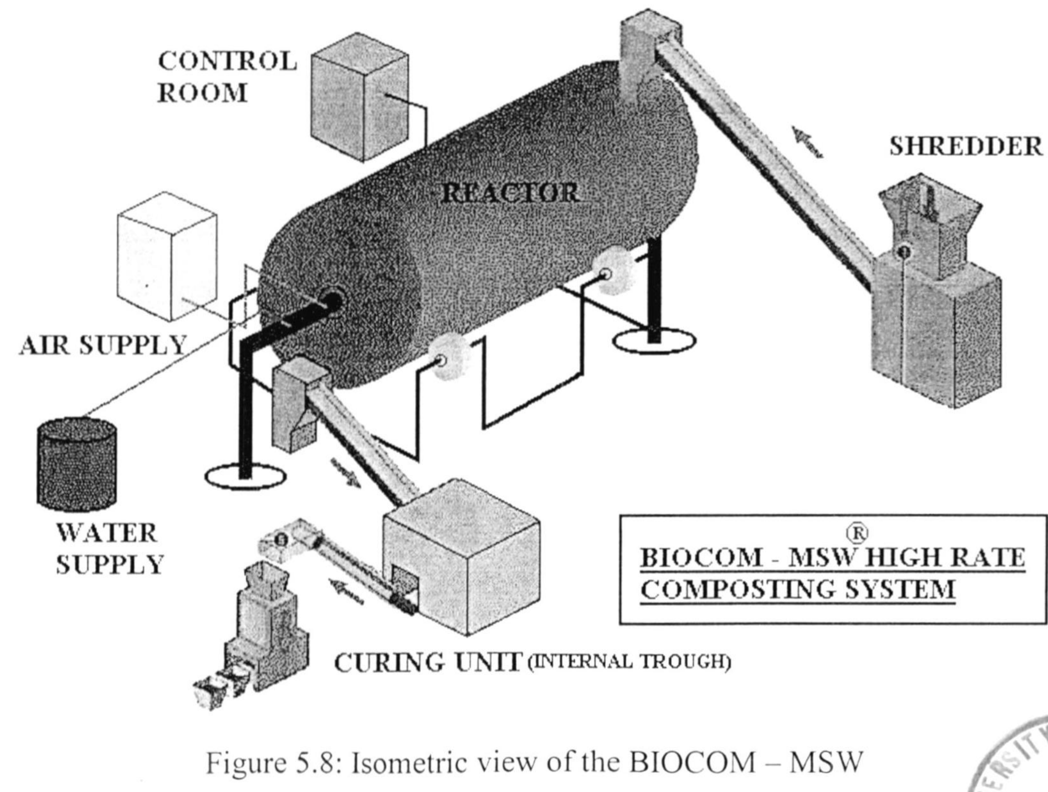


Figure 5.8: Isometric view of the BIOCOM – MSW

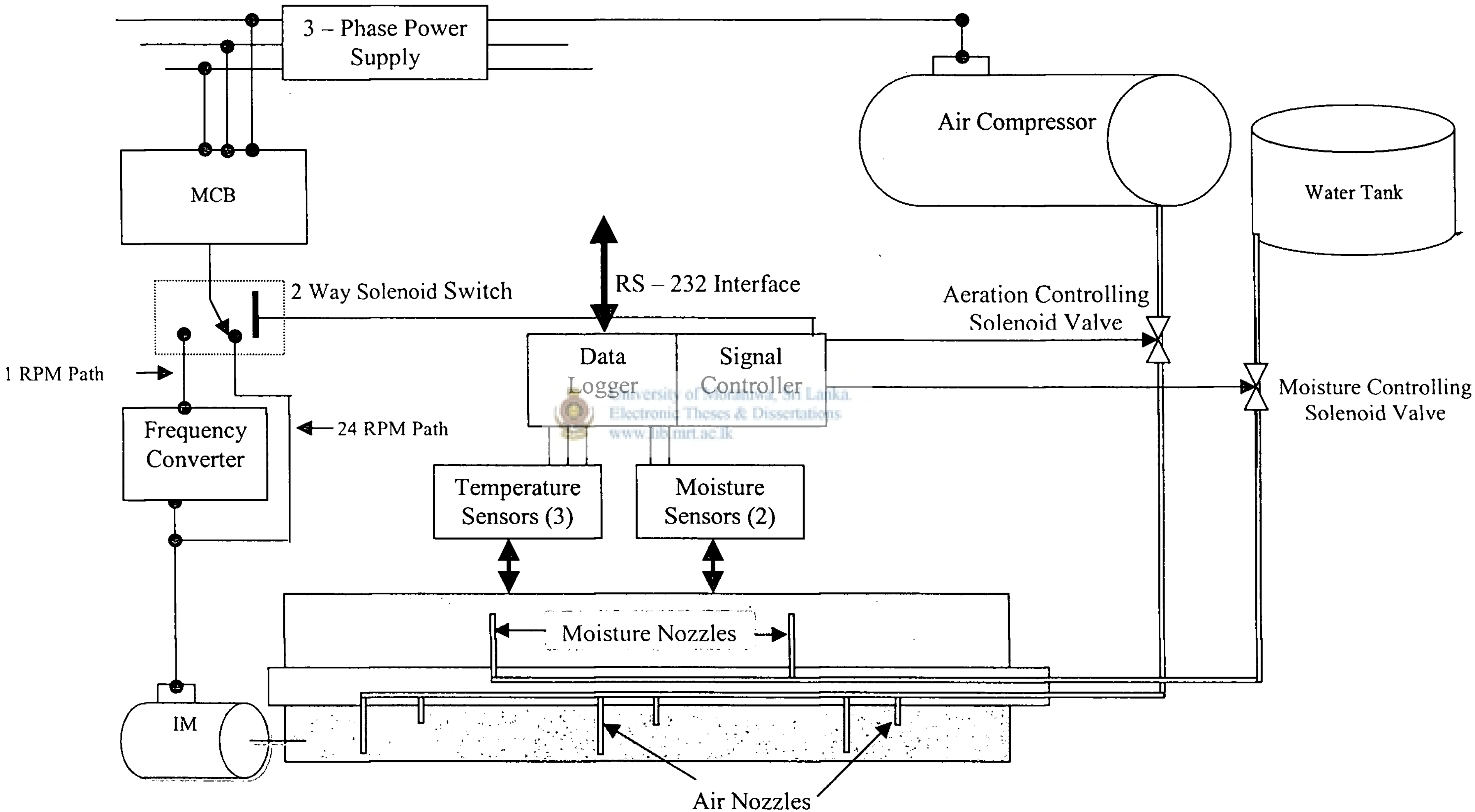


Figure 5.9: Block diagram of wiring, sensor setup, actuators and datalogging

5.3 Operational Characteristics

Since it is possible to sense the current moisture content inside the reactor on real time basis and due control of moisture injection into the system, the moisture content at different stages of composting can be controlled.

Operational speed of the reactor is 24 rpm. Though this is good for the size reduction, it may disrupt the microbial activities during the composting. Therefore, a frequency converter (5.5 kW, ATV - 58HD12M2, Altivar 58, France), country) is used for smooth control of rpm of the induction motor. Hence, it facilitates to vary the speed virtually from zero rpm to the desired rpm. However, in initial trials, the rpm is set to 1 rpm. With optimization with actual running taking place, one could decide the best rpm, which can be run without disturbing the microbial activities.

Using a separate water tank and an air compressor water and air are introduced into the reactor as and when demanded by the integrated control system. This ensures that aeration and moisture conditions will not to be process-limiting factors. Optimum decomposition of the substrate in the reactor is made possible in this manner.

5.4 Fabrication, installation and daily operation

Once the design was completed in May 2001, the fabrication had to be done externally. A suitable workshop was selected by getting three quotations requested based on the design diagram. Jinasena Engineering Technologies was selected for fabricating the reactor considering the available facilities, delivery time and cost.

Design details were given to the workshop in the first week of September 2001 and the fabrication was completed in first week of October 2001. Some of the fabrication stages are shown from figure 5.12 to figure 5.16. The figure 5.12 shows the reactor inside with the spiral, which is used to forward the material, breaking the material during the rotation and to stiffen the reactor shell. Figure 5.13 shows the frame and the reactor. Feeding point and instrumentation pipe are shown in figure 5.14. Driving motor, gearbox, driving shaft and the wheel are shown in figure 5.15. The completed reactor is shown in figure 5.16.

In early February 2001, a suitable site within the campus was selected to install the reactor. The plot of land selected behind the pavilion is shown by figure 5.10 and figure 5.11. The initial request of constructing the structure was realized in late October 2001 to house the whole system. It was necessary to extend the 3-phase power supply up to the installation site in order to give the power to 3 – phase induction motor and other utilities in the system. This was completed in mid December 2001. A compressor and overhead water tanks are installed in the same housing unit. Figure 5.17 shows the reactor placed under the structure. The design, fabrication, instrumentation selection, sourcing and planning etc are now all completed.

It is intended to use the organic fraction of daily collected waste at the university for characterization studies of the system. Initial discussions were held with university medical officer and maintenance engineer in order to implement the system. A concept paper was developed on how to implement the system considering the present waste disposal practice in the university, waste generation sources, composition and daily collection leading to new research areas in solid waste management at the university. This paper presented to the relevant university authorities are presented in Appendix A.

5.5 Different stages of BIOCOM – MSW development

Figure 5.10: Site view from Gate end

Figure 5.11: Site view from opposite end

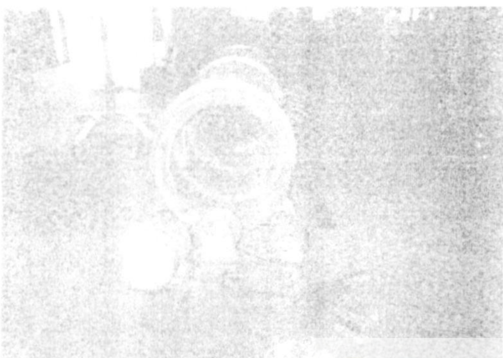


Figure 5.12: Reactor under construction

Figure 5.13: Frame and the Drum

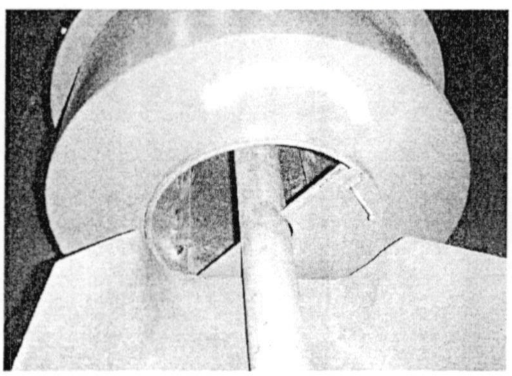


Figure 5.14: Feeding point

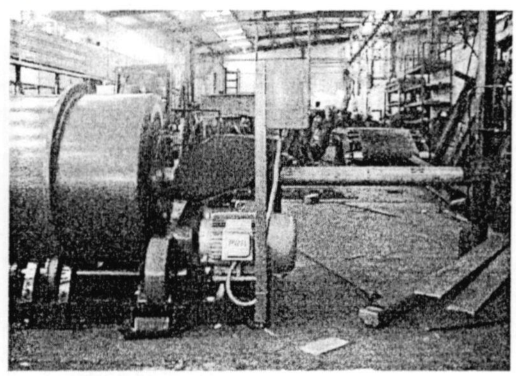


Figure 5.15: Driving motor and gearbox

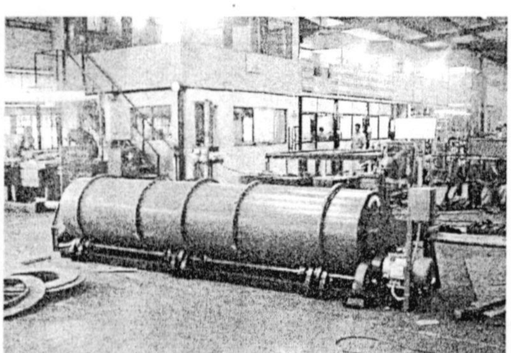


Figure 5.16: Completed Reactor

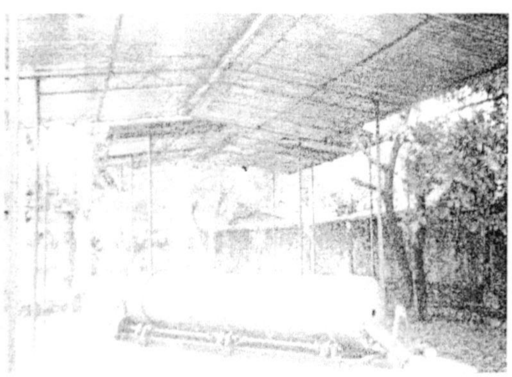


Figure 5.17: Reactor placed under the structure behind the pavilion

Chapter Six

Results and Conclusions

The results are presented in three sections as Review of Solid Waste Management practices in Sri Lanka, compilation of visited existing composting practices and design of high rate composting system.

6.1 Review of Solid Waste Management practices in Sri Lanka.

Waste characterization and compost analysis from typical practices of composting are presented as follows:

6.1.1 Waste characterization

Table 6.1 shows the comparison of biodegradable organic fraction with national average and Atakalanpanna, Hambamtota and Vauniya where random analysis were carried out. It shows the overall organic waste fraction exceeds more than 80 % except in Atakalanpanna case.

Table 6.1: Comparison of Biodegradable organic fraction in different areas

No.	Sample	Bio - degradable Percentage / %		
		Short Term	Long term	Both
01	National average	50.09	37.17	87.26
02	Atakalanpanna	33.34	33.96	67.30
03	Hambantota	75.80	6.08	81.88
04	Vauniya	46.08	34.45	80.53

Density comparison residential vs. commercial in Vauniya is shown in table 6.2.

Table 6.2: Waste density comparison of residential vs. commercial in Vauniya.

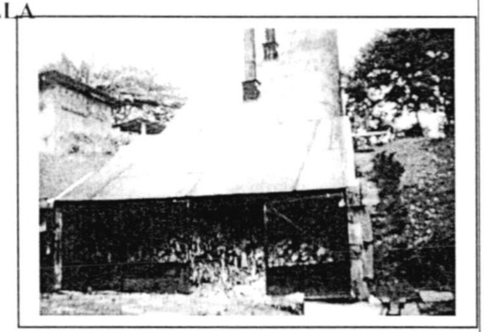
Sample Type	Density (ρ) /(kg/m^3)			
1. Residential	248	220	160	259
2. Commercial	270	210	206	147

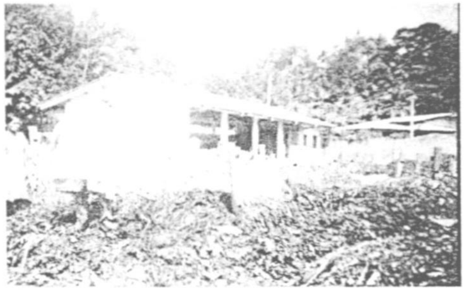
Waste densities at Atakalanpanna and Hambantota were 350 kg/m^{3}and 330 kg/m^3 respectively. In Vauniya average waste density in residential area was 228 kg/m^3 while in the commercial area was 217 kg/m^3.

6.2 Compilation of visited existing composting practices

Information was compiled the visited composting practices in Sri Lanka, paying attention to the method adapted, cost of project, residence time, existing problems, process description and related information on marketing. The table 6.3 summarizes the above description.

Table 6.3: Some Solid Waste Management projects in Sri Lanka

No.	Plant	Technology	Comments
1.	**UNIVERSITY OF PERADENIYA, KALUTHARA, MAWANELLA, DAMBULLA**  *Capacity – 4 t/day,* ***Cost – Rs 5M*** **IN OPERATION**	- Use aerobic conditions. - Back end process. - Natural convection is used to control the temperature of the digesting section. In the digesting part, a simple heat exchanger system is used. - Two chimneys are used to exhaust the hot air from the plant. - Turning is done by using its own self weight of waste allowing them to roll from the top to bottom of the structure. - Duration - 3 months (Including curing).	- No pre-sorting is done at present. - Less space is required. - No human involvement in turning process. - Separation of materials is done as a back end process at present. - Due to poor management, plant is run occasionally in some sites.
2.	**BANDARAWELA**  *Capacity – 10 T/day,* ***Cost – Rs. 1.9M*** **NOT IN OPERATION**	- Open Windrows without shelter . - No sorting, no size reduction had been done. - Duration of Process– 3 months	- Funded ,constructed and ran by the Bandarawela Urban Council. - Selected site was near a school and a residential area - Project has been abandoned due to poor management and technology. - Currently the site is used to dump garbage.
3.	 **ANURADHAPURA – COMPOST PLANT** *Capacity – 10 t/day,* ***Cost – Rs. 8 M*** **(Funded by ADB)** **NOT IN OPERATION**	- Same as Ratnapura and abandoned due to public opposition.	- Project did not implemented. - Project is located in the middle of two water streams. - In order to avoid leachate percolation, riverbank has concreted.

No.	Plant	Technology	Comments
4.	**RATNAPURA COMPOST PLANT**  *Capacity – 15 t/day,* ***Cost – Rs. 9.5 M*** **(Funded by ADB)** **IN OPERATION** **(poor condition)**	• Open windrow without shelter. • Use market garbage as raw materials. • Pre-sorting is done by manually. • Heaps are made by using garbage. After six weeks first turning is done. Then in the interval is two weeks. Turning is done until three months. Every time when turning is done 10 liters of water is added. After final turning, the product is stored for curing. Then do final sorting & sieving. • Composting area is concreted • Residence Time – 3 months	• Poor quality of the product (1kg of compost contains 100~200g of sand) • Inappropriate technology has been used (open windrow – without shelter, in a heavy rainy area). • Due to poor process operation, severe odor problem. • No proper wastewater treatment method is used. • Very poor attention for employees.
5.	**NUWARAELIYA COMPOST PLANT** *Capacity – 10 t/day,* ***Cost – Rs. 18.26 M*** **(Funded by ADB)** NOT **IN OPERATION** 	• Same technology has been used as in RATNAPURA.	• Very poor attention for site selection. • No coordination among responsible authorities. • A failed technology has been replicated. • Wastewater has been discharged to a highly use water stream. • Due to strong public protest, project was abandoned after running only 26 days.
6.	**HORANA – COMPOST PLANT**  *Capacity – 10 t/day,* ***Cost – Rs. 3.3 M*** **(Funded by CEIF)** **IN OPERATION**	• Windrow with a shelter. • Use market garbage as raw materials. • Pre-sorting is done by manually at the site. • Then materials are shredded, conveyed to composting area and then heaps are made. • Turning is done by moving to next bins. • After final turning, the product is stored for curing. Then do final sorting & sieving. • Composting area is concreted. • Residence Time – One and half months.	• No wastewater treatment is done before discharge. • Curing seems to be not enough. • Compare with others, reasonably good management. • Quality analysis is required.

No.	Plant	Technology	Comments
7.	**BADULLA – COMPOST PLANT** *Capacity – 6 t/day* **IN OPERATION** 	☛ Windrow without a shelter. ☛ Use market garbage as raw materials. ☛ Pre-sorting is done by manually at the site. ☛ Heaps are made by using garbage. Turning is done six weeks intervals. ☛ After final turning, the product is stored for curing. Then do final sorting & sieving. ☛ Composting area is not concreted. ☛ Residence Time – Three months.	☛ Poor product quality. ☛ Lot of sand addition due non-availability of concrete floor in the composting area. ☛ No monitoring is done for temperature. ☛ Planning to use a multi chopper for size reduction. ☛ Leachate & odour observed. ☛ No leachate treatment or quality analysis available.
8.	**VAUNIYA COMPOST PLANT** *Capacity – 6 t/day,* ***Cost – Rs. 8M*** **(Funded by GTZ)** **IN OPERATION** 	☛ Windrow with a shelter. ☛ Use market garbage as raw materials. ☛ Pre-sorting is done by manually at the site. ☛ Then materials are shredded. ☛ Heaps are made by using garbage. ☛ Turning is done 3 days interval. ☛ After final turning, the product is stored for curing. ☛ Then do final sorting & sieving. ☛ Composting area is concreted. ☛ Residence Time – Three months.	☛ No wastewater treatment is done before discharge. ☛ Decomposition is not uniform. ☛ Most of the infrastructure is available. ☛ Well-designed plant. ☛ Quality analysis is required. ☛ Shredder does not have spare parts locally and it is German product.

6.2.2 Lessons learnt

During the field studies, following factors or combinations of them observed as the major cause of concern to fail the most of the project.

1. Poor planning and coordination among the responsible organizations.
2. Use of inappropriate technologies.
3. Long lead-time of composting process.
4. Weak management structure and lack of accountability.
5. Low quality of the products.
6. Large pieces are fed to composting plants without size reduction.
7. Insufficient cooperation from the residents, administration and workers.
8. Less attention to waste handling workers by the administration and general public.
9. Lack of source separation and poor collection methods.
10. Use of inappropriate vehicles / machinery.
11. Recycling has not been followed wherever possible.
12. Poor identification of suitable sites to set up plants.
13. No proper waste characterization and generation have been assessed.

Table 6.4 shows the composition analysis of typical practices of composting in Sri Lanka.

Table 6.4: Composition analysis of random compost samples

Sample No.	**pH**	**Electrical Conductivity (μS/m)**	**Moisture Content (%)**	**Organic C / (%)**	**N / (%)**	**C/N ratio**	**P_2O_5 (%)**	**K_2O (%)**
01	7.3	2.86	28.79	13.09	1.19	11.00	0.80	2.45
02	8.5	2.65	25.86	22.36	2.89	7.74	0.80	3.03
03	7.9	0.29	35.75	7.00	0.41	17.07	0.25	0.20
04	6.9	3.50	56.79	15.21	1.71	8.89	0.65	1.15
05	7.9	2.79	20.15	10.54	1.15	9.17	4.55	3.43

When look at the Table 6.1, samples 1,2,4 and 5 show a significant C/N ratio reduction. However, it is suspicious to decide that as a good end point indicator of the process, since it is unknown the starting C/N ratio. Probably it has started with low C/N ratio and hence the final low value. Except the fourth sample, all the others have shown good moisture content. This is important in terms of quality of the product, when it comes to marketing.

Table 6.5: Heavy metal content random compost samples

Sample No.	Heavy Metal / (mg/kg) Dry basis				
	Cd	**Cr**	**Cu**	**Ni**	**Pb**
01	ND	ND	33.5	ND	23.1
02	ND	33.7	27.3	ND	17.2
03	ND	16.0	15.2	ND	24.2
04	ND	ND	29.4	ND	ND
05	ND	21.1	119.5	ND	53.0

ND: Not Detected

The fifth sample has the highest amount of Copper (Cu); this compost was made out of unsorted solid waste. Since the contamination is higher than the sorted solid waste compost.

The results how ever do not show significant contamination from heavy metals. This is not much surprising, as Sri Lankan municipal solid waste is not much contaminated with solid wastes arising from industry due to the absence of a significant industrial base. It is also a positive indicator that with careful preparation this type of municipal solid waste stream could easily be turned into a valuable soil conditioner unlike in developed countries.

During the visual inspection of samples did not show any small pieces of glass, metals or plastic. However, it is unavoidable to prevent from these foreign matters, when compost is made from mixed garbage.

In order to figure out the heavy metal concentration, it is needed to get large number of samples from various parts of the country. Then it can be decided the degree of contamination due to heavy metals in compost made out of solid waste.

6.3 Design of high rate composting system

This research was able to analyze and develop a high rate in vessel composting system. The design of the in-vessel composting system (BIOCOM-MSW) was carried out with the following requirements and this enables to carry out further characterization studies using a rotating drum composter under tropical conditions.

i. Development of a uniform temperature distribution throughout the matrix.
ii. Development of a system with constant moisture distribution in the reactor.
iii. Uniform airflow throughout the substrate matrix.

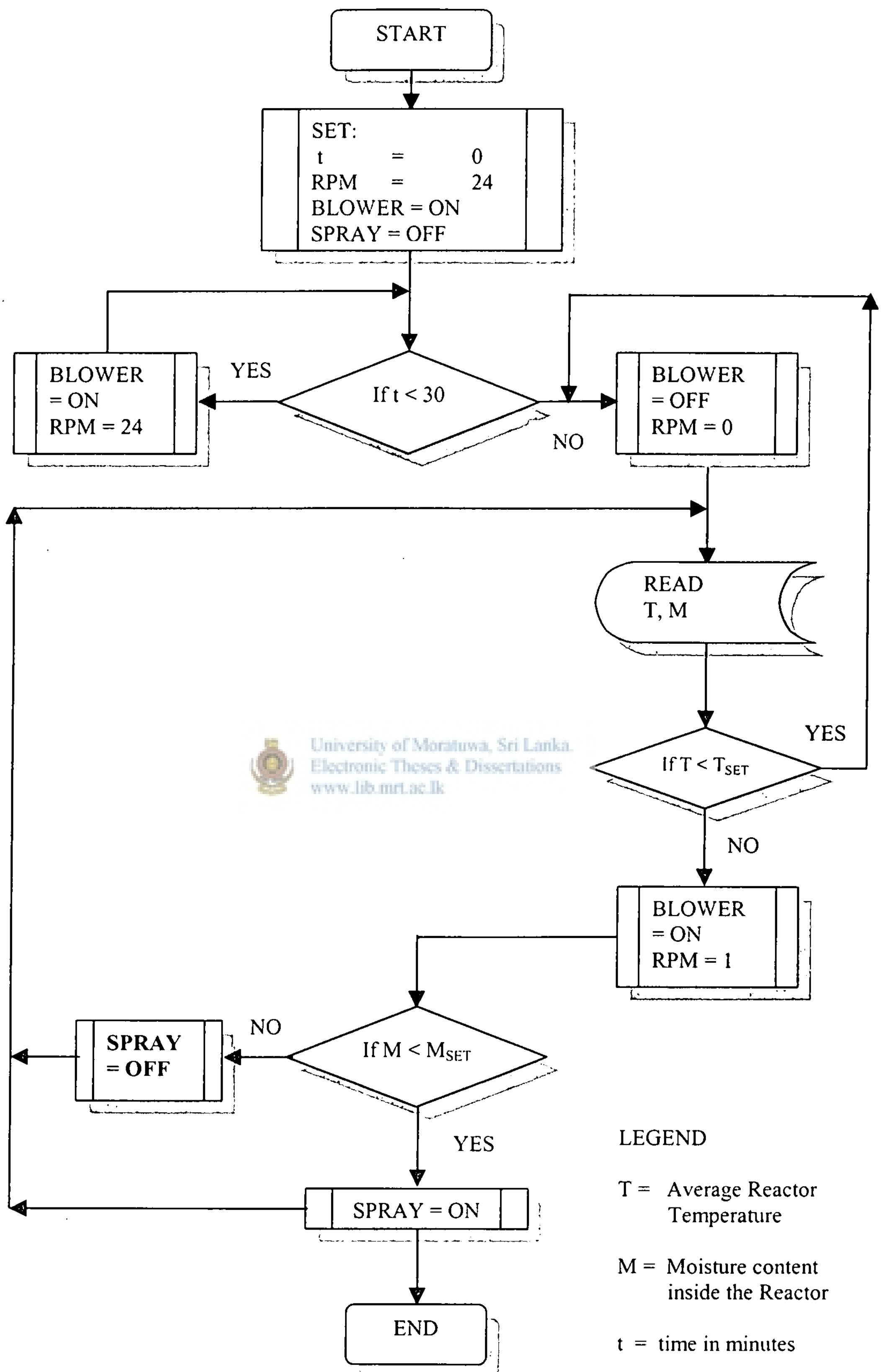
The above three factors have been constrained in most of the composting systems studied and observed during this study. Therefore, different feedstock such as sewage sludge with paper, municipal solid waste, yard trimmings and tree cuttings can effectively be composted using this pilot plant. Further, pathogen inactivation in composting is an important factor, but most of the designs do not ensure this requirement or expected to take place by default. However, intermittent rotation of this reactor helps to mix the materials uniformly and hence the substrate is subjected to uniform temperature distribution through out the process.

Table 6.7: Operational characteristics of the BIOCOM - MSW

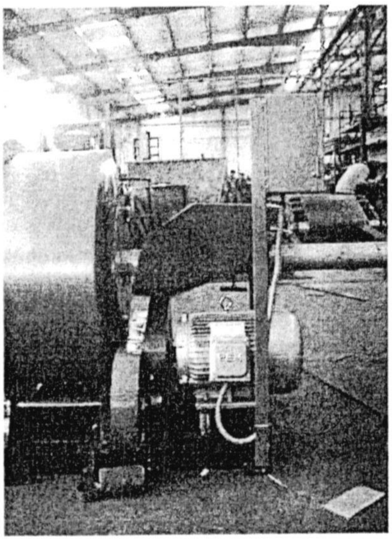
No.	Parameter	Units	Value
1	Start up RPM (Mixing)	RPM	24
2	Intermittent rotation	RPM	1
3	Temperature Set Point	°C	60
4	Moisture Set Point	%	60
5	Mixing time	Minutes	30
6	Capacity	kg	690

The algorithm shown in section 6.4 controls the whole process. However, it is possible to control the RPM in different stages such as 2,3,4 up to 24 RPM by presetting the frequency converter.

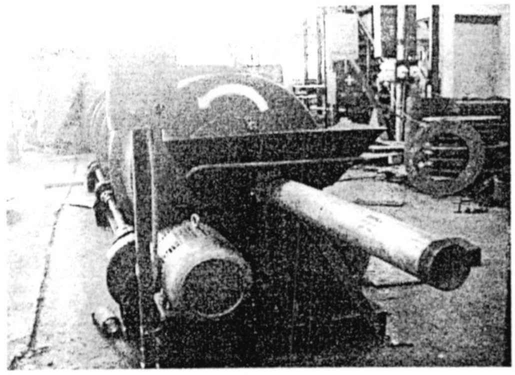
6.4 BIOCOM – MSW Control algorithm



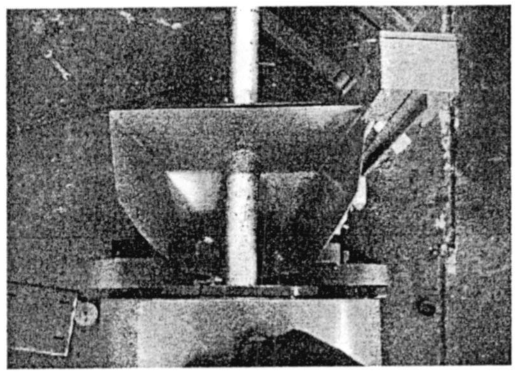
6.5 Different views of BIOCOM - MSW



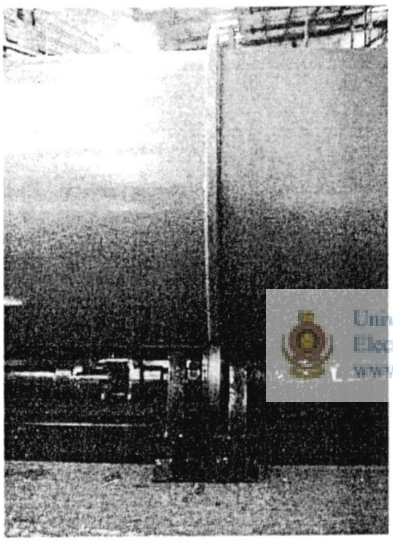
Feed, Gearbox and Motor



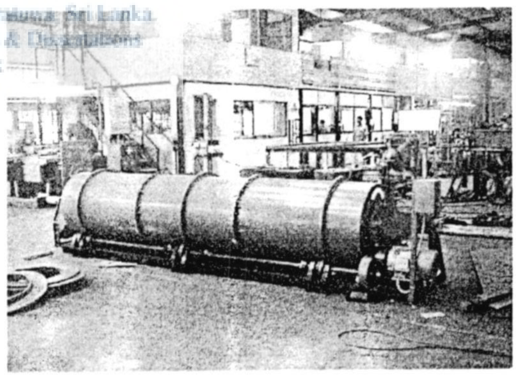
Rear view with instrumentation pipe



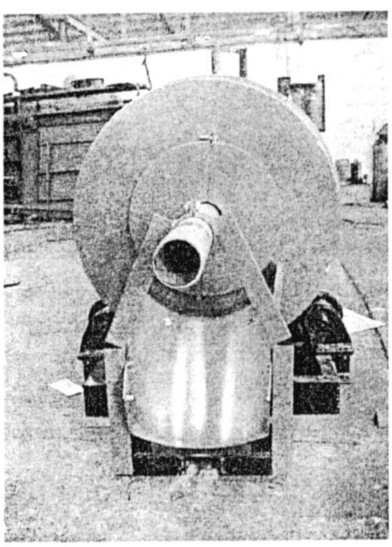
Rear view with instrumentation pipe



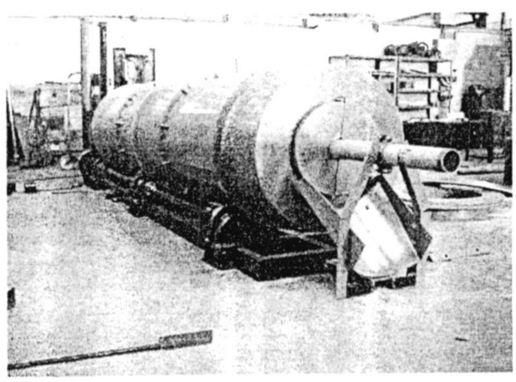
Universal joints and supporting wheel



Rear view with instrumentation pipe



Front view with outlet



Side view with instrumentation pipe & outlet

Chapter Seven

Recommendations for future studies

Future work is presented as follows in general with solid waste management cum composting for national benefit and the system development.

7.1 Suggested future work for general solid waste management

This thesis addressed the solid waste management problem by reviewing the existing solid waste management status in Sri Lanka and development of an in-vessel composting technology. In order to have a better understanding in those areas, it is required to do detailed studies on following areas. It was felt during the study much of the statements are made with knowledge available from other systems especially systems in temperate climates. The following areas offer rich areas for further investigation;

- Detailed waste analysis in regional wise.
- Detailed study on compost quality and contamination of heavy metals.
- Identification and creation of new markets for compost. (Linking of organic matter problem in plantation sector with composting cum solid waste management)
- Compost standards and market needs
- Leachate characteristics studies.
- Health impact of present disposal practices.
- Environmental cost benefit analysis in solid waste management rather than the economic analysis based on present system.
- New tools to increase the public awareness.

This would help in making better decisions on solid waste management for the policy makers and implement timely required rules and regulation to safeguard, not only the environment but also the hidden costs that government has to bear in safeguarding public health in the medium to long run.

7.2 Suggested work with the BIOCOM-MSW system

- The BIOCOM-MSW should be run with different sets of operating parameters and a database generated for composting characteristics.

- It is required to find different environmental needs according to the microbial population such as bacteria, fungi and actinomycetes at different stages of composting. Then, it could be related with the existing process control strategies or need to be modified as required.

- It is needed to find the optimum output based on the volatile matter loss during the intervals of feeding. Otherwise, undigested materials also will be taken out and be needed more curing time.

- The development of a process model for composting under in-vessel composting. The process model can be employed in scale-up work or in further optimization.

- Comparison of compost quality characteristics between two process types based on the already available data from this study.

- It is required to study the plant cost comparison with other options, energy utilization per unit output, process characteristics according to the substrate and fabrication material selection for long term durability (at least 15 years).

In order to take the advantage of the O_2 feedback control system the units require expensive O_2 sensors. However, Rutgers system needs only a temperature feedback control system, which is inexpensive to build. Applying Rutgers strategy in-vessel composting gives new dimensions to composting control strategy. All the control strategies are based on either oxygenated condition or temperature dependant aeration conditions. However, moisture loss due to those processes is not encountered. It was shown in the literature review, that mainly fungi, which require higher moist environment than the bacteria, degrade lignin, cellulose and hemicellulose. It is necessary to determine why it takes such a long time to degrade those materials and whether it is due to the limiting of moisture in the latter part of the composting process. This reactor set up helps to identify those areas by having the necessary air nozzles and the moisture injectors to the composting matrix at various intervals. If ways of accelerating the digestion could be implemented the process will stand to benefit.

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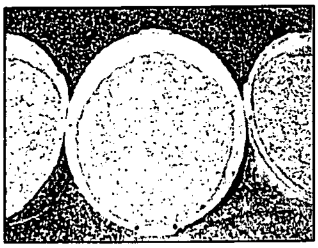
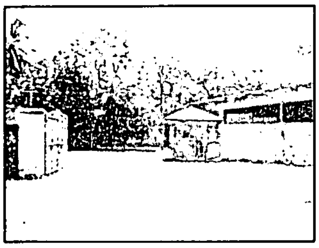
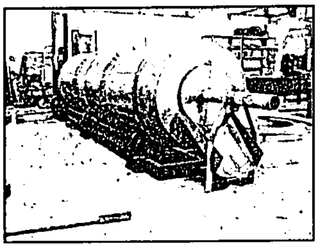
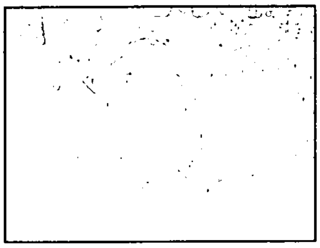



BIOCOM – MSW
at
University of Moratuwa

Present Waste Management at the University:

Currently all waste generated at the university is dumped as it does in other part of the country. However, this research infrastructure can be utilized effectively to treat the organic fraction of the waste produced at the university.

Strength:

University Research Grant	=	Rs. 444,000.00
National Research Council	=	Rs. 865,000.00
EA1P	=	Rs. 100,000.00
USAEP	=	Rs. 400,000.00

<u>Sustainability of BIOCOM – MSW at University of Moratuwa depends on...........</u>

Security of the plant equipment:

As the plant is placed in more remote place from the central part of the university, it is highly vulnerable to the loss of removable parts of the plant. Therefore, it is very much needed to safeguard the equipment from such events in order to utilize it properly. (Research as well as for treating the waste in the university)

NOTE: During the period of construction of the structure, the contractor reported, three GI sheets were lost.

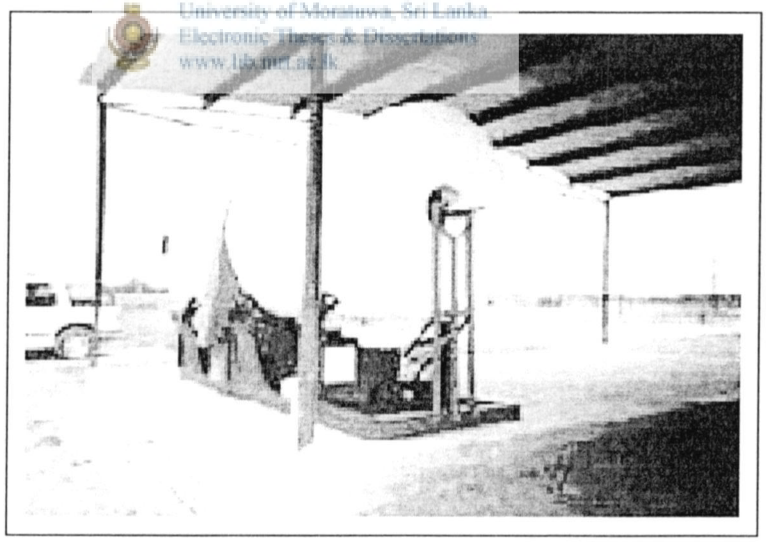


Figure 01: In due course Fixed BIOCOM – MSW at UOM

Raw Materials:

1. Organic fraction of canteen waste (Pre and post consumer).
2. Grass Clippings from the university lawns.
3. Sawdust (from university carpentry works / outside).
4. Shredded used paper

Separation:

All Canteens are given two bins to separate daily waste as organic and inorganic. Then the organic fraction is sent to the site daily using present collection (cart) system.

NOTE: Two different colors are used for bins to distinguish the material to be put. Green will be used for the organic while the brown is used for the others.

Sorting at Site:

Further sorting is done at the site and the remains send back to the existing dumping site using the same carts.

Mixing:

Sorted waste is mixed with sawdust and grass clippings as required. Every effort is made to keep the moisture at 60%.

Processing:

The reactor is filled up to the 2/3 rd of its total volume. First, materials are shredded using the reactor, running at higher (24) rpm. Then it is reduced to 1 to 2 rpm as required by using Frequency Converter.

Post processing:

Decomposed material is further cured in static piles for two to three weeks before use. This is done using an accelerated curing unit.

Awareness:

For the successful operation of BIOCOM - MSW, it is required to separate the waste before processing. In order to achieve this, students / canteen operators / employees are made aware of separation of waste as much as possible at the source of generation. For this, posters and spot demonstrations are done while ensuring the maximum active participation of the stakeholders of waste generation at the university.

NOTE: It can be formed a group of students who intend to do environmental engineering in future and it is possible to set up "the concept of open environment learning center" base on this research site. This would prepare and enable the students to understand the problem of solid waste management / wastewater in an interactive way getting our own example within the university. On the other hand, this could be used to demonstrate how an organized system could manage this burden problem in the country in an effective manner.

Daily operations:

1. Separated organic fraction of the waste is transported to the site daily.
2. The rest of the materials are sent to the existing dumping site.
3. The operator should weigh the incoming material and mix with other bulking agents as required. (Necessary training & formulae are given)
4. Then, the mixed materials are directed to either shredder or to the reactor directly as the case may be.
5. Before switch on the reactor motor, it should make sure that all three phases are live by observing the indicator bulbs.
6. If the material is directly fed to the reactor, then it should be running at 24 rpm for two to three hours as required for the size reduction of the matter. Then, it should switch on to the lower rpm (1 - 2rpm) without disturbing to the microbial activities inside the reactor.
7. Once the material is taken out from the reactor, it should direct to the curing bins properly for further decomposing.
8. Temperature inside the reactor is logged automatically using a small temperature control unit later on. Initially the data logger will do this.
9. Once the daily operations are finished, the plant should be cleaned as directed by the daily maintenance schedule and should keep the place tidy.
10. Any remaining material, which can not be used in the process, should be collected to the bin at the site and the following day it should send to the dumping site.

NOTE: Machine Preventive & Maintenance Schedule, Daily Activity Schedule, Site Upkeep Schedule, Daily Incoming Material Inventory and Product Output Inventory are prepared as required for the optimum operation of the plant.

Management:

Chief Medical Officer (CMO)
Maintenance Engineer (ME)
Public Health Inspector (PHI)
Technical Officer (TO)

Research opportunities:

1. Co-composting of different substrates which currently make problem of disposing such as sewage sludge, sawdust, waste paper etc.
2. Possibility of use of mobile waste treatment unit where the problem occurs or which need to be addressed immediately.
3. Most of the LAs in Sri Lanka produce less than 10TPD of waste, which helps to design small mobile units which ensures the public acceptance, less space and consisted product quality etc.
4. Introduction to farms (Ambewela, Weerawila & Ridiyagama etc) and Tea plantations where Organic Tea is produced.
5. Possibility of demonstration of Internet based control strategy
6. Use of centralized control system for monitoring a cluster of waste treatment units serving various parts of the country.

Figure 02: Future Mobile BIOCOM – MSW?

University – Industry link:

University – Industry (BIOCOM – MSW Inc.?) based commercial venture to sort out the current problem of solid waste management in its capacity.

Expanding the research opportunities in waste management at the university using the income generated out of the venture.

NOTE: These pictures are from a research carried out at University of Texas – Commerce in 1992 and it is an on-going research. This is what exactly, we can do at the University of Moratuwa in Sri Lanka without having foreign experts, but our own experts and resources available in the university / country.

www.mrt.ac.lk/solid.waste.research….?

This web page can be incorporated with the existing university web site. And, would be a place to understand and see the situation of solid waste management and research & development in Sri Lanka. During the research period of BIOCOM – MSW, it can be linked with the data logger / controller to see the data obtained and some analyzed information for the academic interest. Main features would be….

- Solid waste problem in the country.
- How the University of Moratuwa contributes for finding a feasible solution to the burden problem (various researches).
- Research facilities in this area at the UOM.
- How university manage the solid waste problem itself.
- Capacity building at NGOs and CBOs for solid waste management.
- Composting principles.
- Available technological options and selection.
- FAQs in Composting.
- University – Industry research opportunities in solid waste management.
- National Solid Waste Management strategy.
- Useful other web links.

Appendix I

Networking of BIOCOM – MSW with
www.mrt.ac.lk/solid.waste.research

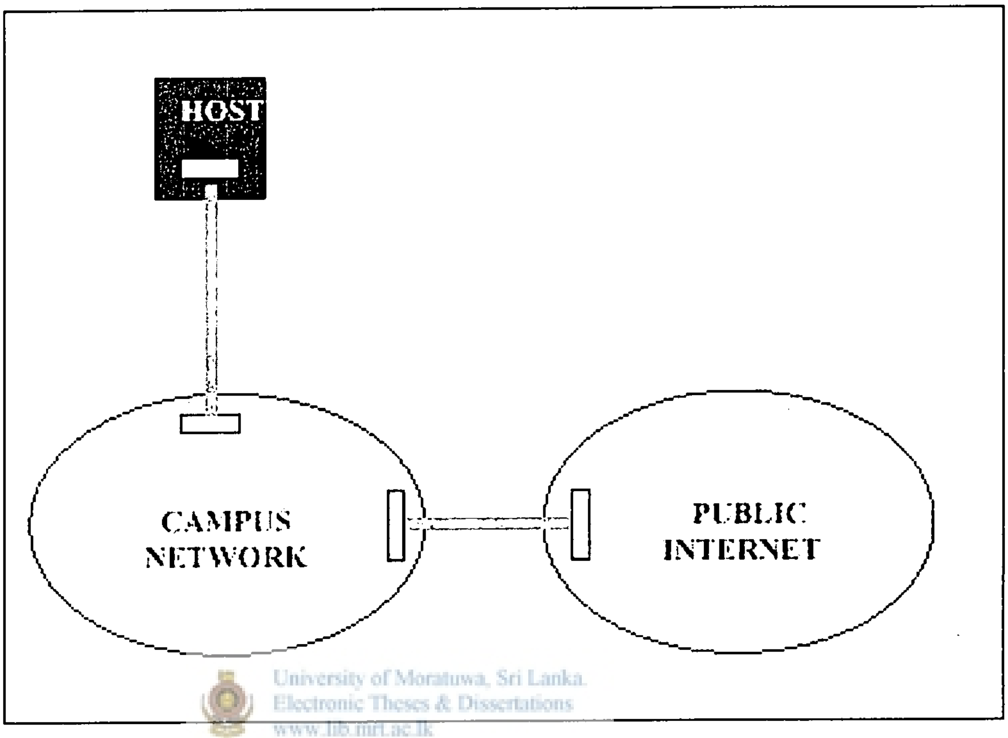


Figure 03 : General arrangement of network