

MECHANICAL BIOLOGICAL PRETREATMENT - A CASE STUDY FOR PHITSANULOK LANDFILL IN THAILAND

Josef O.Tränkler, Renuka M. Ranaweera, and Chettiyappan Visvanathan

UEEM Program SERD and WEM Program, SCE

Asian Institute of Technology

P.O. Box 4, Klong Luang

Pathumthani 12120, Thailand

ABSTRACT

A sanitary landfill under operation since the beginning of 1999 has been the objective of our analysis. All available information of this site served as input for a detailed analyzing. Further to that results derived from semi-scale lysimeters and lab-tests have been used to refine the comparison with respect to the forecast. As pre-treatment method windrow composting was discussed under given boundaries. After a period of 9-12 months degradation the material is supposed to be disposed of in that landfill. Leachate production and gaseous emission of both the composting and the landfill under tropical conditions influenced by monsoon have been assessed. Consequently gas production potential of both processed and untreated waste was determined for the comparison.

Pre-treatment, i.e. mechanical biological processing or simple composting of MSW (not for the production of quality compost) is suggested as one option for improving the landfill performance in the tropical region viz. Thailand by reducing landfill emission.

The outcome of the comparison and a prediction over a timeframe of 20 years proves the benefits of a reasonable emission reduction by a pre-treatment process. The cumulative pollution load from leachate can be diminished for COD and nitrogen compounds by 77 - 89%. The overall gas formation can be reduced by more than 35 % and the global warming potential will be abated by more than 70%. Main benefit of waste pre-treatment will be achieved in combination of composting and a landfilling with a simple methane oxidation system in the top layer. The total waste mass will be diminished saving landfill volume and achieving a lifetime extension of the landfill. Landfill after care will thus be reduced significantly.

LANDFILL AND EMISSION CONTROL

Concerning landfilling most Asian countries have been facing similar problems, e.g. in Thailand or India more than 90% of landfills are open dumps. However, landfilling is considered to be the most effective method of solid waste disposal in developing countries

if adequate sites are available. The upgrading of existing sites and the sound operation as well maintenance will be major issues of solid waste management system. The cost associated with landfill construction and operation practiced in developed countries, and indefinite post closure control of gas, and leachate require substantial amount of money and technical skills for post closure activities. Therefore, the design of an appropriate landfill technology calls for a comprehensive approach on alternatives. Suitable and feasible landfill operations are most sought after and especially those to curtail the post closure aftercare period. Biological pre-treatment of solid waste by a simple homogenization and composting is a reasonable option.

Biological pre-treatment of solid waste is claimed to have advantages such as shortening the monitoring period, production of lower concentration leachate requiring simpler treatment, reduction in landfill gas production rates and space conservation due to fast degradation and consequently better compaction. In the following investigation the benefits of such a pre-treatment are discussed and first results of the process' implementation are reviewed.

COMPARATIVE STUDIES LANDFILL

Sanitary landfill under study

Consideration and general conclusions on the potential of MSW pre-treatment shall be drawn from the sanitary landfill of Phitsanulok in Central Thailand. The incoming municipal solid waste's composition shown in Figure 1 demonstrates around 60% LOI at high moisture content in the range of 62%. A remarkable plastic content in an average range of 30% wt. (res. 36% dry matter) has to be noticed. The selected site is very typical for the region. It features a design of bottom liner and final cover both of compacted clay of reasonable low permeability, and an efficient leachate drainage system but no gas drainage system. Due to the limited input and the relatively small size, which is very common for the region (Ashford et al., 2000) intensive gas recovery is hardly feasible and the degree

of mechanization for compaction is very limited, so far. Additionally the high plastic portion restricts the compaction to solely 300-400 kg/m³. The specific situation of the said landfill serves as input to evaluate various approaches on how to reduce the overall gaseous and liquid emissions. A wider assessment corresponding with the scope of a lifecycle analyses as been reported by Hertel and Rommel (2002) and Soyez (2000) couldn't be considered due to lack of reliable

data.

Based on actual landfill performance and simulations consequences of simple windrow composting prior landfilling are appraised. The system and its performance is described by Maak (2001). The emission potential of pre-treated and subsequently landfilled waste is compared to that waste only landfilled without prior pre-treatment.

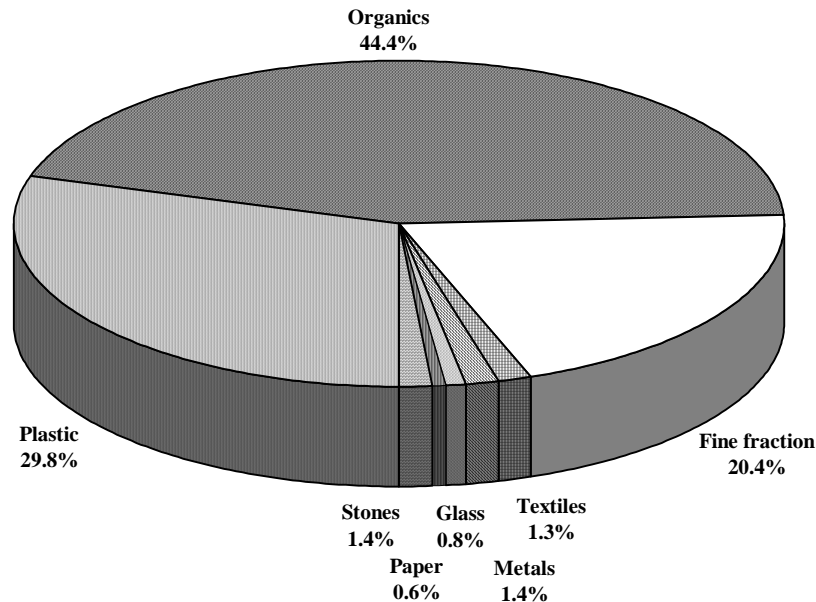


Figure 1: Average domestic waste composition sampled at the landfill site

Landfill performance under monsooning conditions

Thailand ails monsoon conditions, which are best characterized by a rainy season of eventually high intensity rainfall. However, it has been observed that under the local conditions 220–250 days per year show up with no rain at all and a distinct arid period of about 4 months. A medium temperature of 28°C, and a solar radiation of 18.8 MJ/m²/day. results in high evaporation rates of 43-52%. Both the distinct rainy season and the more or less arid period influence the landfill performance to a very high extent as they do impel any kind of composting pre-treatment. Thus the water balance of the landfill and the windrow composting are of special focus for this assessment. As been observed, the variation of season both retards biological decomposition and accelerates the processes. A phenomena that can be only resolved incompletely and shall not be integrated in the outline of this comparative case study, which is established on equivalent conditions.

Landfill emission boundaries

For this comparative case study the emission

potentials have been modelled for period of 20 years based on available on-site data. The case study compromises the disposal of municipal solid waste being disposed of as it is and waste composted over 1 year and subsequently landfilled for another 19 years superposing identical conditions. Like in lifecycle analyses 1 ton of wet waste at an initial moisture content of 62% and a LOI of 60%, respectively is chosen as a functional unit to which all comparisons are interrelated. As the waste decomposes transformations occur, which alter specific properties like moisture content, bulk weight, degree of compaction, and field capacity. These changes have been considered in the computation of the results. Likewise the precipitation and resulting flows, which are related to a specific area have been converted to the functional unit.

Landfill emission data

Published data on leachate composition have been thoroughly surveyed subjected to plausibility checks and reprocessed to serve as a basic input. In order to determine reasonable discharges and loads the

database was extended by further analyses. Especially data from older landfills in the region have been lacking for a comparison. For that reason further information was distilled from other sources (Tränkler et al 2001).

The same approach has been made to evaluate the resulting leachate composition from pre-treated waste and a critical review performed to use the results for the following. At this stage assumptions had to be made to close the gap and to get a reasonable output. Hypotheses have to be verified by real data and refined in later steps, however, are regarded as adequate for the intended appraisal. The leachate comparison has been condensed to two constituents

namely chemical oxygen demand (COD) characterizing organic composites and ammonium-nitrogen ($\text{NH}_4\text{-N}$) labeling inorganic compounds.

Figure 2 shows the predicted variation of COD. The composition undergoes a variation according to the distinct stages of decomposition. Starting with an extremely high concentration of dissolved organic matter (acidogenic phase) will decrease during the course of time, however, maintain on a relative high level. The decrease of these constituents is paralleled by an increase of ammonia during the stable methanogenic phase (Fig. 3). The pre-treated material reveals much lower concentrations due to aerobic degradation compromising nitrification.

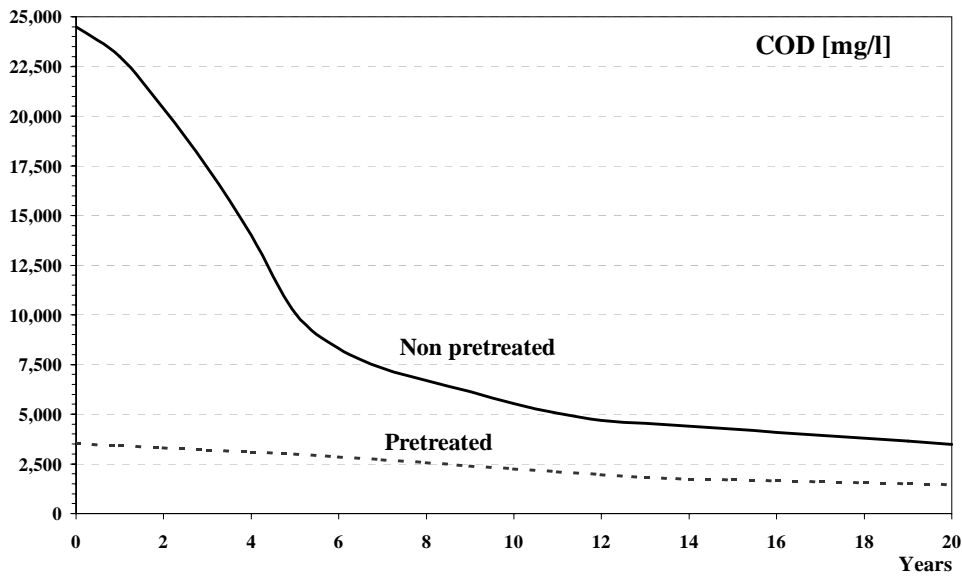


Figure 2: Variation of COD concentrations for non processed and pre-treated MSW

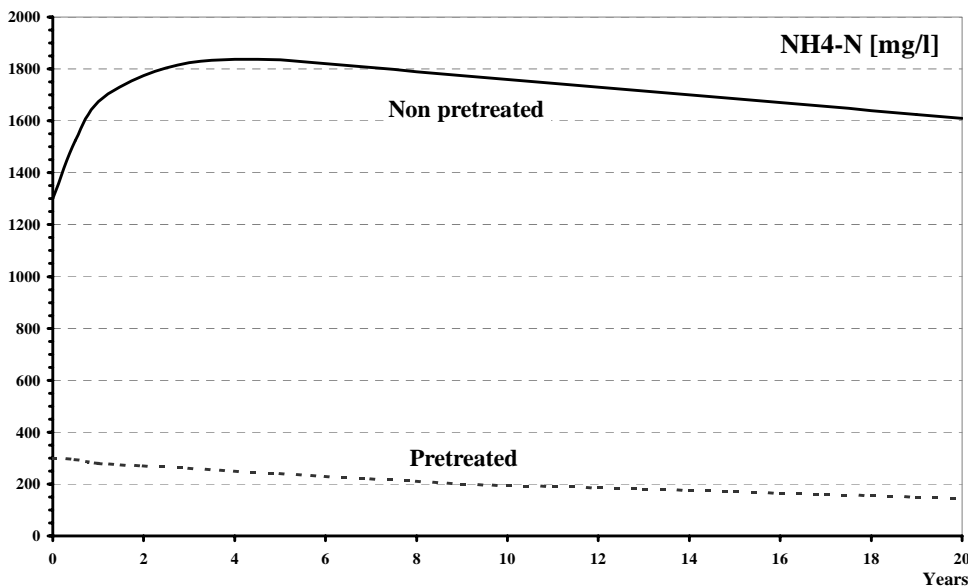


Figure 3: Variation of $\text{NH}_4\text{-N}$ concentrations for non processed and pre-treated MSW

Leachate from composting

During composting leachate and polluted run-off is generated. The qualities of this wastewater during the pre-treatment process have to be considered, too. In case of composting no time related variation of the leachate could be taken into consideration. The total pollution load was calculated based on an average initial leachate generation of 65 L/ton MSW at a medium COD concentration of 35,000 mg/L and $\text{NH}_4\text{-N}$ concentration of 1000 mg/L. The run-off dilutes the COD to an average concentration of 500 mg/L and $\text{NH}_4\text{-N}$ to 100mg/L respectively (Ranaweera and Tränkle, 2001).

Waterbalance of landfill and pretreatment system

The leachate flow that would be generated in that landfill was predicted by performing a waterbalance, applying the Hydrologic Evaluation of Landfill Performance -HELP- model (Schroeder et al., 1994). For that purpose the local long-term weather data have been appraised, soil and waste properties determined, and landfill design data have been compiled. The application of the model in tropical climate like Thailand has raised several issues like effect on water balance by the large variation of short-term rainfall, which might have greater input into runoff than infiltration. The evaporation

component of the water balance might be over-estimated, as it is dependent on solar radiation and vegetative growth (hardly any).

Due to insufficient observed data for leachate generation, the model could not be calibrated for the local situation. However, the trend of leachate generation on a long-term basis being satisfactory has been anticipated.

The leachate production of the landfill varied in the range of about 8-19% of the precipitation, the production rate being 0.5-0.8 liter/m²/day. For the further determination and analyses the outcome of the HELP simulation over a timeframe of 20 years based on the climatic data from 1979-1999 has been employed.

For windrow composting the main fraction of the water balance is related to the leachate. On a medium basis it accounts for 55% of the precipitation with a range from 47-61%. The leachate contributes to a very minor part to the storage and will immediately mix up with run-off. The field capacity of the compost material is the governing that factor. The evaporation contributes to a water loss of around 37-45%. For this case study the worst case conditions have been selected (Tränkle and Manandhar, 2000).

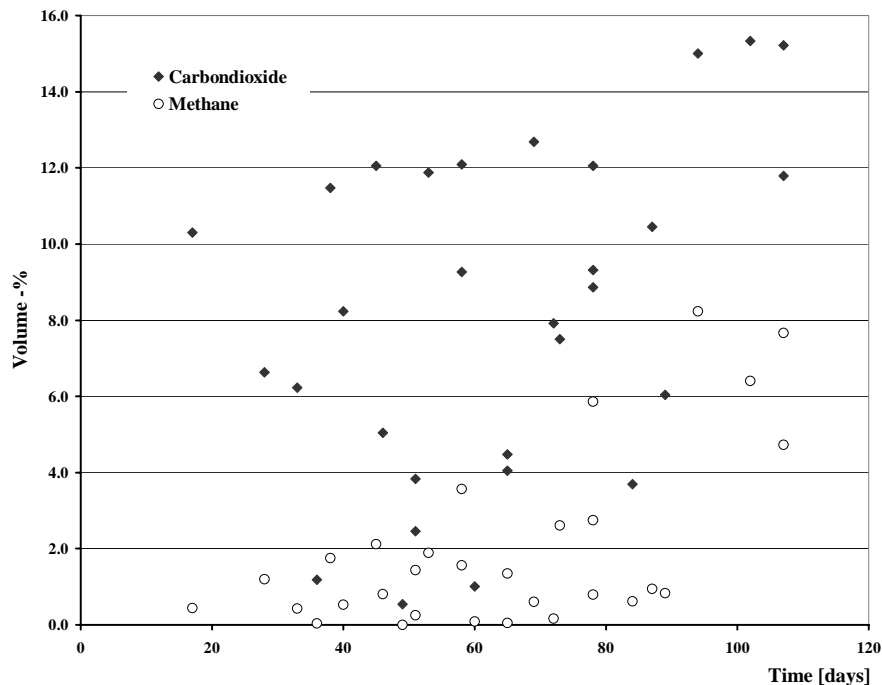


Figure 4: Off-gas composition of a tested windrow system

Off-gas balance of landfill and pretreatment system

For the assessment of gaseous emissions we have to make use of a different approach. The time related gas production with respect to flow and composition cannot be simulated but the total generation is attained. For the anaerobic landfill system it is assumed that over a timeframe of 20 years 90% of the total potential is emitted. It is known that the entire gas potential of bio-mass of various composition accounts to 500-550 NL/kg VS at an average of 55% methane and 45% carbon-dioxide. Given the functional unit of 1,000-kg wt waste a total gas generation is expected in a range of 115,000 NL.

Pre-treated waste will generate less landfill gas. The effective reduction of biogas generation was demonstrated by landfill simulation in a column experiments. These laboratory experiments revealed a total gas production of 20–22 NL/ kg DM. Provided the same boundaries and considering a reasonable amount of a anaerobically degradable fraction pre-treated waste generates a potential gas volume of around 24,500 NL per functional unit shall emerge. Around 75% shall be released throughout the proposed timeframe of 20 years.

Due to aerobic and/or anaerobic decomposition of organic matter both carbon dioxide and methane or carbon dioxide only is generated. Aerobic composting is supposed to produce predominantly carbon dioxide. However most recent results (Clemens cited in Soyez, 2000) and own observations indicate that windrow systems will emit a moderate amount of methane (Fig. 4). It has been estimated that 10 kg of methane per 1,000kg wet waste is generated. Own analyses verify singular values up to 12Vol-%. However, the average values ranges around 3 Vol.-%. Accordingly a methane emission from a simple non-aerated windrow system is fixed at 6.5 kg/1,000 kg wt of waste. Thus methane contributes to 13.5% to the gas flow from a windrow composting process. The total gas flow potential estimation is based on the glucose equation. A total gas flow from the composting is predicted to be 67,000 NL.

RESULTS AND DISCUSSION

The main objective of pre-treatment is the reduction of pollutants' emissions. However, it is not sufficient to consider only the emissions from landfills. To assess the effectiveness, the total pollutant emissions from pre-treatment process as well as those of the final disposal of pre-treated waste have to be evaluated and compared with the outcome of landfilling only. The pros and cons can be better underlined by looking more closely in the water balance, the pollution load, and greenhouse gas emissions.

Leachate generation and management

Reason for the organic pollutant load of leachate is the uncontrollable decomposition of organic waste. By simple but controllable processing a significant reduction of both gaseous and liquid emissions could be achieved. To assess this pollutant reduction potential of pre-treated waste the cumulative load of COD and NH₄-N over 20 years was computed using leachate flow rates from the water balance simulation and average concentrations (Fig. 2 and 3).

The resulting cumulative COD and NH₄-N loads over 20 years of landfill operations, for pre-treated and untreated wastes are given in Figure 5 and 6. The reduction in pollutant potential of pre-treatment is rather evident. The pre-treatment process comes out with a peak load during the intensive open composting. This initial COD peak accounts to around 18% of the total 20-years load. However, during the acidogenic phase of landfilling a highly polluted leachate containing mainly volatile fatty acids is generated. It is calculated that within the first two years of landfilling a higher organic load might be discharged than being totally generated from pre-treated waste. The pre-treatment reduces the potential load fixed by single stage landfilling to roundabout 22 %.

Given the time variations of nitrogen concentrations a similar result is to be anticipated for the NH₄-N load. The initial NH₄-N peak load for pre-treated waste accounts to around 20% of the total 20-years load. And there is little difference between the initial load emerging from the pre-treatment process and the first phase of the landfilling. With times the gap between pre-treated and non pre-treated waste increases. Reason for that gap is nitrification that is occurring during the aerobic composting. A main portion of the NH₄-N compounds will be oxidized. Whereas anaerobic landfilling leave nitrogen compounds unchanged and due to progressive degradation maintain these constituents even on an elevated level. Finally the cumulative NH₄-N-load of the pre-treated waste is predicted to arrive at 13% of the non-processed one. High-level nitrogen compounds govern the leachate composition of conventional landfills until a non-predictable final stage. Compared to such conditions the leachate from pre-treated waste arrives at a reasonable level within a foreseeable timeframe. In combination with a decent organic pollution load it is likely easier treatable. However, even at lower pollution load an appropriate leachate treatment system is required. Though, the application of low technology treatment systems like wetlands might be more suitable and adequate notwithstanding the appearance of priority pollutants.

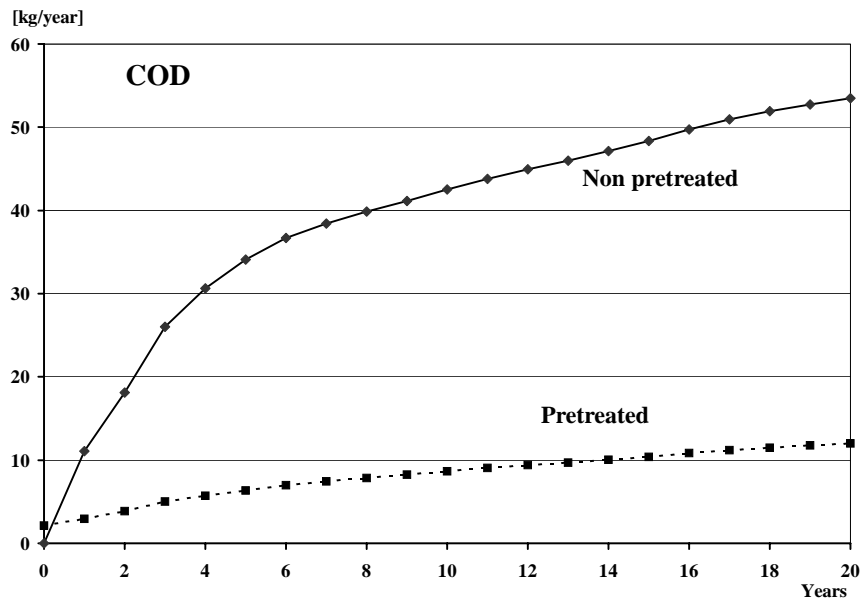


Figure 5: Comparison of the cumulative COD load over a period of 20 years

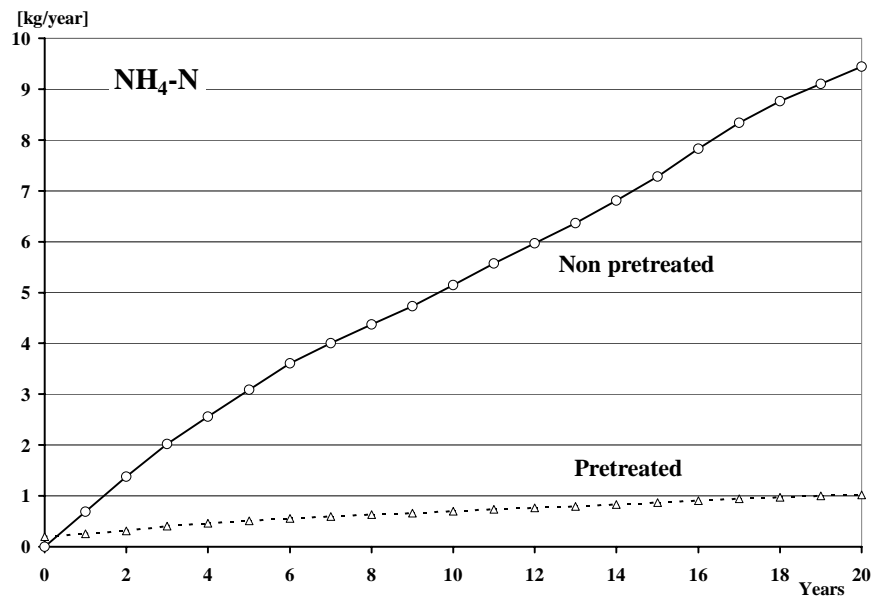


Figure 6: Comparison of the cumulative NH₄-N load over a period of 20 years

Greenhouse gases

During landfilling organic matter is decomposing and aside of polluted leachate landfill gas is produced. As the selected pre-treatment process diminishes the organic content it is rather evident that the gas generation during the anaerobic phase of landfilling is reduced significantly, too. Consequently, the main green house gases CH₄ and CO₂ respectively are

reduced. However, for an accurate comparison it has to be considered that during the biological pre-treatment process CO₂ and CH₄ is emitted. Assuming an almost parallel progress within the given timeframe and considering the lack of information about the time variation of gas generation only the total rates are compared. The comparison is based on global warming potential (GWP) units. The GWP of

CH₄ is 21 times more with respect to CO₂. The quality of untreated waste and pre-treated waste on GWP is presented in Figure 7. An effective reduction of biogas is demonstrated. It is quite obvious that pre-treatment can reduce the GWP by nearly 2/3. Although less effective in comparison the total amount of both CO₂ and CH₄ emitted during composting is important in considering overall reduction in greenhouse gases. Nearly the same quantity of CH₄ will result from the oppositely processed wastes. However, the overall quantity of gas produced arrives for the pre-treated waste at 63 % of that without pre-treatment. Flaring might be considered as an option to ease the negative

climate impact. However, the praxis of regional landfill shows that landfill gas is scarcely collected. Particularly an insufficient gas collection system leads to non-controllable greenhouse gas emissions. Therefore and if the gas flow rate for the pre-treated waste is as low as predicted the application of a methane oxidation layer will be sufficient to guarantee zero methane emission. Methane oxidation will be supported by the tropical climate and elevated temperature, too. With the combination of pre-treatment and a passive system of methane oxidation gaseous emissions will be primarily limited to CO₂ at reduced flow rates.

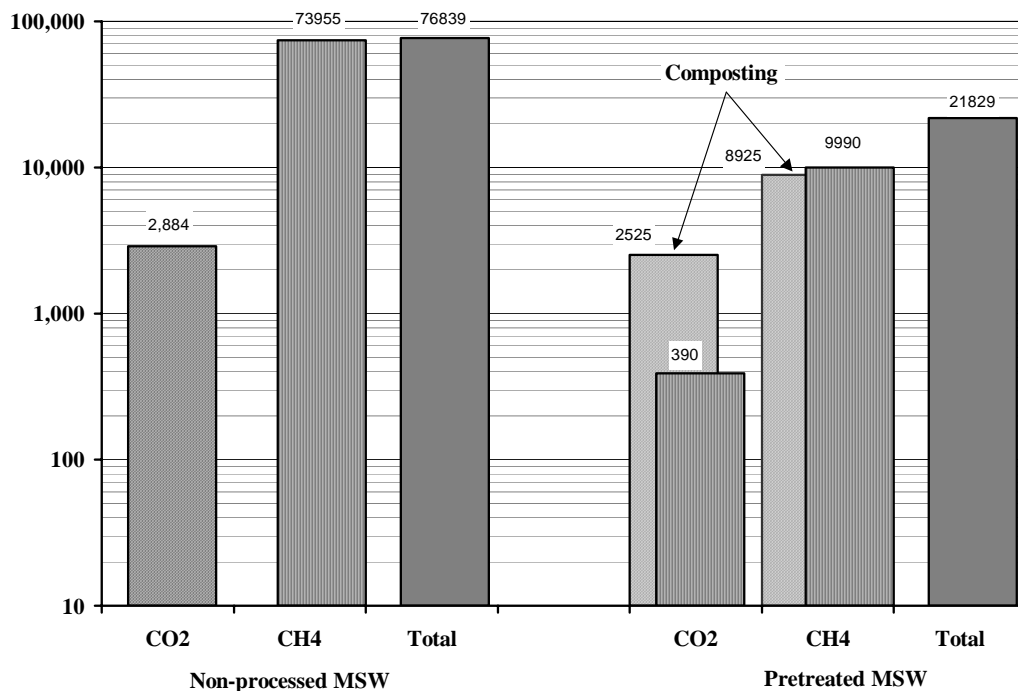


Figure 7: Global warming potential of non-treated and pre-treated waste (logarithmic scale)

CONCLUSIONS

Pre-treatment, i.e. mechanical biological processing or simple composting of MSW (not for the production of quality compost) is suggested as one option for improving the landfill performance in the tropical region viz. Thailand by reducing landfill emission. Pre-treatment technology has the advantage of selecting its components according to the requirements of particular waste stream, climate conditions, desired quality of output and economy. The advantages of the pre-treatment could be stressed by looking more closely in the pollution load originating from landfill leachate and greenhouse gas emissions. By properly controlled pre-

treatment of MSW, landfill emissions can be reduced significantly.

The pollution load from leachate can be diminished for COD and nitrogen compounds by 77 and 89% respectively. However, the load requires an adequate treatment throughout the operational time of the landfill. Due to the pre-treatment the nitrogen load decreases essentially thus the leachate treatment need not be focused primarily to the oxidation of such inorganic compounds. Furthermore an appropriate wastewater treatment like activated sludge system plus wetlands might be considered as suitable. Within the chosen timeframe of 20 years the overall gas formation potential can be reduced by more than 35 % and the global warming potential will be abated

by more than 63 %. Main benefit of waste pre-treatment will be achieved in combination of gas reduction and a simple methane oxidation system. Additionally about 40-50% of waste mass is diminished saving landfill volume and achieving a lifetime extension of the landfill. Landfill after care will be reduced significantly.

Further improvement shall be achieved in maintaining the composting process in an aerobic status. Given the high moisture content of the waste, intensive rainfalls, a minimum of void space plus a reasonable plastic fraction static pile composting

shows limitation. Either forced aeration over a certain period or turning might render the problem. However, additional efforts have to be made and more energy will be consumed.

Further improvement might be obtained if an assessment more like a lifecycle analysis can be performed. The lack of data concerning energy consumption and other relevant environmental features hampers such an endeavor. Nevertheless with the on-going full-scale operation information will become available, which allow a further fine-tuning of the statements expressed.

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