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# ANALYTICAL APPROACH TO OPTIMIZING THE DESIGN OF WINDROW COMPOSTING PLANT

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## ABSTRACT

**The present study was a pilot project initiated in Chandigarh to discuss the adept schemes for successful co-composting of green waste and kitchen waste (food & fruit waste), its designing aspects, composting area sizing,capital and operational cost. In particular, the process design components such as solid wastes recovery, segregation, compost stabilization, curing and storing were analyzed for the treatment of campus municipal solid waste calculated as 0.48 $m^3$/day garden waste, 0.13 $m^3$/day food waste and 0.05 $m^3$/day fruit and vegetable waste. The present study was pioneer attempt to accurate the design and its study results to the development of a prototype of composting facility to achieve carbon foot print benefits and sustainable zero waste future.**

**KEY WORDS :** Sustainability, Aerobictreatment, Windrow composting, Design, Cost analysis

## INTRODUCTION

In the present era, the accumulation of solid waste was the massive global environmental challenge in developed countries due to indiscriminate population growth with high population density (Aziz *et al*., 2018). India generates about 68.8 million tonnes municipal solid waste (MSW) per annum which would increase to 300 million tons by the year 2047, mainly due to rapid expansion of cities with massive migration and floating population towards urban centre. In this context, the city beautiful, Chandigarh with large percentage of floating population from satellite towns (Mohali, Panchkula and Zirakpur), generate 370 metric tons/day MSW. The city beautiful sourced large number of landfills and dumping sites. The present study was pioneer attempt to devise and highlight best organic waste management strategies to achieve carbon foot print benefits using windrow composting, an eco-friendly, biological and biochemical aerobic integrated waste management strategy used to reduce the volume and mass of solid organic wastes (Adhiraki *et al*., 2009; Rana *et al*., 2015; Vigneswaran *et al*., 2016; Barthod *et al*., 2018; Fan *et al*., 2019. Lee *et al*., 2020; Sharma, 2021). The aim of the present study was to develop an the optimum design of windrow composting plant and to develop a prototype of composting facility to achieve sustainability in the management of the kitchen waste (food, fruit waste) with grass clippings in different combinations to establish the relationship between physico-chemical parameters (temperature, moisture content, pH and C:N ratio).

## MATERIALS AND METHODS

### Study Site

The open site windrow composting plant (30.7583° N, 76.7841° E.) of 0.5 tonnes per day (TPD) capacity, situated in the campus of Post Graduate Government College for Girls, Sector-11, Chandigarh was the source of the present study.The total municipal solid waste (MSW) of the campus was 100kg/day.

The windrow plant consists of screening facilities, solid waste separator, charging and composting units.

### Raw Material

Green waste and Kitchen waste (Fruit and vegetable waste) collected from food services (canteen, mess) of the campus were used as raw material for the windrow composting plant. The bulking agent (grass clippings) was added as basal layer on brick lined (15 cm) charging unit, which was sequentially alternate with food and kitchen waste (30 cm) in three different layers. The repetition of the layers was done till the cumulative pile reached 1.5m high.

**Windrow composting**

Windrows produced safe, stabilized and nutrient enriched soil conditioner, which minimize the negative environmental impact of traditional underground pit composting. However, the membrane covered windrows with basal layer bulking agent (grass clippings) generate micro-positive pressure, reducing the emission of GHGs ($CH_4$, $CO_2$, NO), hence increasing the windrow plant efficiency to degrade recalcitrant compounds while monitoring the physico-chemical parameters (temperature, moisture content, pH, C:N ratio) with reduction in its operational cost. To start with, the land was identified and windrows prepared. The design and the arrangement of windrow is shown in Figs. 1-2. Windrow composting which involves the piling of linear rows of the composting material at an open space which were turned manually to make the organic waste bio-stable, organoleptic and compatible with sustainable agriculture and floriculture operations (Sharma, 2021).

**Analytical techniques**

About 200 g of samples was collected on weekly interval from windrows and analysed for physico-chemical parameters (Temperature, pH, moisture content and C/N ratio). For measuring compost pH, raw samples were mixed with de-ionized water at a weight ratio 1:10. The mixture was shaken for 1 hr, allowed to settle and pH of the clear supernant was measured with digital pH meter. The collected samples were oven dried at 105 °C for 24 hrs and loss of weight was taken as the moisture content. The 'Reo Temp' compost thermometer was used to weekly record the temperature data at four cardinal points of the windrows , over the period of 240 days. The sample from organic compost was taken and heated at 70 °C for 24 hours and subsequently cooled and powdered. The 2 g sample taken from blended mixture was placed in a small aluminium cone and a CNHS-O analyzer was used to determine C/N ratio.

## RESULTS AND DISCUSSION

With the increase in population and rapid socio-economic development, a tremendous increase in the municipal solid waste (MSW). The average uncompacted density of leaves and grass means plant material, Food waste and Food and fruit waste respectively was 104kg/m$^3$ (Davis and Cornwell, 2006; Aziz *et al*., 2018); 193 kg/m$^3$ (Zhonglei *et al*., 2021); 544.2 kg/m$^3$ (Sall *et al*., 2016). In the current design, the collected leaves and grass clippings was 50% of MSW (100 kg/day), i.e 50% of 100kg=50kg/day;

Volume of the waste=Mass/Density;

V=50/104=0.48 m$^3$/day.

Similarly, Food waste was 25% of the total MSW (100 kg/day)

25% of 100 kg-25 kg/day

Volume of Food waste=25/193=0.13m$^3$/day

However, the third substituent, fruit and vegetable waste was 25% of the total MSM (100 kg/day);

Volume of fruit and vegetable waste=25/544.2=0.05 m$^3$/day;

Hence, the Total volume=0.48+0.13+0.05=0.66 m$^3$/day

**Dimensions of the windrow Composting Site**

1. Volume of the material to be composted=0.66 m$^3$/day
2. Composting Period (Holding Time) = 240 days
3. Total volume of waste in windrow = 240x0.66 = 158.4 m$^3$
4. Dimensions of Windrow:
   Length=8 m
   Width=6 m
   Height=1.5 m
5. Volume of windrow=LxWxH=8x6x1.5=72m$^3$.

Aziz *et al*., (2018), who explained different sections of windrow (triangle, trapezoida and semicircle). The trapezoidal section being the economical design. However, our findings show proper waste management with stabilized physico-chemical parameters was better observed with the rectangular windrow section (Figs.1-2). The rectangular windrow plant with volume of 72 m$^3$, was proved to be cost effective, as each plant infrastructure mainly consists of indigenous material and its cost auditing comes out to tune of twelve thousand five hundred only.

**Evaluation of Composting**

Presently, the sustainable municipal solid waste

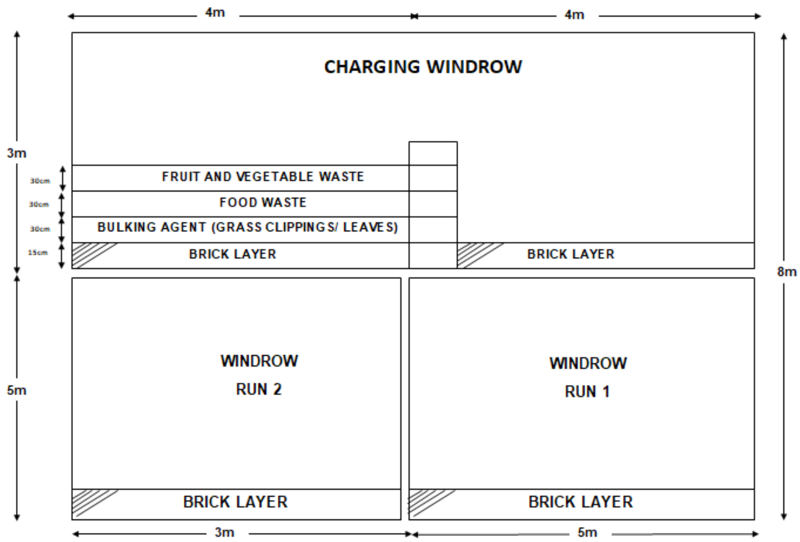


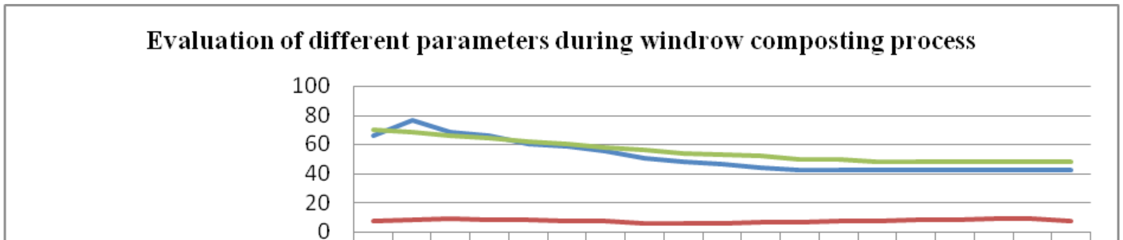

**Fig. 1.** Design of windrow plant

**Fig. 2.** Layout of windrow plant

management was demonstrated through the windrow composting, a waste-treatment technology, which is greatly influenced by physico-chemical parameters (temperature, moisture content, pH and C:N ratio) during the composting process. According to Tchobanoglous and Kreith, (2002), the factors that most influence the composting process were the characteristics of the composted material and their profiles during the composting process are given below:

**Temperature and pH**

The observation of data reveals that the initial temperature of the compost was 60 °C and it rose to over 76.2 $^0$C in second week (8$^{th}$ day) and the temperature decreased to 68 $^0$C, 66 $^0$C, 60 $^0$C in fourth, fifth and sixth week respectively. In the whole period of composting, the persistence of thermophilic temperature above 55 °C for minimum period of 7 weeks was recorded in temperature profile (Fig. 3). Moreover, the windrow piles were turned and mixed at frequent intervals and it was observed that the windrow pile temperatures dropped to ambient temperature immediately after each turning, however, it returned to the thermophilic phase (above 55 °C) within two subsequent days and maintained for several days The temperature drops to 48 °C in the ninth week and reached constant mesophilic phase (42 °C) thereafter till compost maturity (Kumar *et al.*, 2010). The pH prolife shows basic level to start within windrows depicts an elevation from 7.2 to 9.06 in the third week and remains alkaline till 7$^{th}$ week and this rise of pHwas due to generation and emission of ammonia, which pronounced microbes activity at thermophilic stage (Sundberg *et al.*, 2004). The pH dropped from 6.2 to 5.8 respectively in eight and ninth week attributed to production of organic acids and their volatization due to prolonged thermophilic phase and attained neutral value at 7.6 at the end of composting process (Fig. 3). This system with bottom up aeration system due to bricklined grass layer (bulking agent) and cover membrane, was conductive in maintaining micro-positive pressure in windrows and making piles aerobic and odourless in compliance with the earlier reports (Tognetti *et al.*, 2007; Adhikari *et al.*, 2008; Kumar *et al.*, 2010; Awasthi *et al.*, 2018; Hemidat *et al.*, 2018; Kim *et al.*, 2018; Waqas *et al.*, 2018; Oviedo-Ocana *et al.*, 2019; Rupani *et al.*, 2019; Yang *et al.*, 2019; Al-Alawi *et al.*, 2020; Al-Rumaihi *et al.*, 2020; Chahar *et al.*, 2020; Cristina and Leahu, 2020; Jalalipour *et al.*, 2020; Ma *et al.*, 2020; Pena *et al.*, 2020;




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperaturedegree celcius | 66 | 76. | 68 | 66 | 60 | 58 | 55 | 50 | 48 | 46 | 44 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |
| pH | 7.2 | 8.0 | 9.0 | 8.5 | 8 | 7.4 | 7.3 | 6.2 | 5.8 | 6 | 6.4 | 6.8 | 7.4 | 7.8 | 8 | 8.2 | 8.7 | 8.7 | 7.6 |
| Moisture Content | 70 | 68 | 66 | 64 | 62 | 60 | 58 | 56 | 54 | 53 | 52 | 50 | 50 | 48 | 48 | 48 | 48 | 48 | 48 |

**Fig. 3.** Evolution of Temperature (°C), pH and Moisture content during windrow composing

Rastogi *et al.,* 2020; Voberkova *et al.*, 2020).

**Moisture Content**

The moisture content of organic waste at the time of inoculation as piles was 70% and moisture content reduction was due to well developed pore structure of bulking agent. BA porous nature constitutes aerobic habitat for microbial proliferation, hence enhanced microbial activities results in rise of temperature. The high temperature in windrows evaporates compost water, stabilizing the final moisture content in the range of 48-50% (Fig. 3). The moisture content in present study shows inverse relation with the increase time interval. The decreased moisture content was positive sign of decomposition and it gives more stable, odorless and mature compost. The perusal of literature reveals that the moisture content above 60%, resulted in water logs which prevent air penetration in the pile, resulting in the leachate production and emit foul odor (Adhiraki *et al*., 2009; Kumar *et al*., 2010; Iqbal *et al*., 2015; Zhang *et al*., 2016; Barthod *et al*., 2018; Hemidat *et al*., 2018; Al-Rumaihi *et al*., 2020; Cristina and Leahu, 2020; Jalalipour *et al*., 2020; Lee *et al*., 2020; Pena *et al*., 2020; Rastogi *et al.,* 2020; Voberkova *et al*., 2020).

**Carbon/Nitrogen(C/N) ratio**

The Carbon to Nitrogen (C/N) ratio, an important parameter provides an optimal conditions for composting process. AC/N ratio in range of 25-30 has been found to be optimum for windrow composting process. The prolonged thermophilic phase resulted in the lower C/N ratio which enhanced the nitrogen leaching and nitrate mobilization making the windrows anaerobic. However, in present studies, the micro-positive pressure resulted due to basal layer bulking agent and windrow cover membrane, increased the C/N ratio to 25, in compliance with the earlier studies (Zhu, 2007; Chang and Hsu, 2008; Francou *et al*., 2008; Xiao *et al*., 2009; Kumar *et al*., 2010; Iqbal *et al*., 2015; Yan *et al*., 2015; Artemo*et al*., 2018; Cáceres *et al*., 2018; Hemidat *et al*., 2018, Ayilara *et al*., 2020).

## CONCLUSION

Windrow composting is an alternative solid waste management system, used in recycling of organic waste into stable organolepticorganic compost with improved physico-chemical parameters. The blue print of technique design is beneficial in developing countries attributed to cost effective and easy to implement.

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