PURE OXYGEN-BASED MUNICIPAL SOLID WASTE (MSW) BIO-STABILIZATION: ENERGY, ENGINEERING, ENVIRONMENTAL AND PROCESS SAFETY ASPECTS*

Sabino De Gisi1, Francesco Todaro1, Carmine Carella2, Gabriella Fedele2, Michele Notarnicola1

1 Technical University of Bari, Department of Civil, Environmental, Land, Building Engineering and Chemistry (DICATECh), Via E. Orabona n. 4, Bari 70125, Italy
2 CISA S.p.a, Contrada Forcellara S. Sergio, Massafra (TA) 74016, Italy

Abstract

Today, in Italy, mechanical-biological treatment plant (MBT) using pure oxygen are few and with limited knowledge of the functioning. With the intent of strengthening the state of knowledge, this contribution deepens the main energy, engineering, environmental and process safety aspects of a pure oxygen-based full-scale bio-stabilization system treating unsorted municipal solid waste. The activities were conducted at the Massafra MBT plant (Apulia Region, Southern Italy) with a treatment capacity of 220,000 tons per year. After the assessment of the energy consumption related to the conventional aeration system, representing, in this way the “baseline scenario”, the study discussed the main design aspects for a safe operation of the pure oxygen system.

Keywords: bio-stabilization, mechanical-biological treatment, municipal solid waste, pure-oxygen

1. Introduction

Bio-stabilization represents the biological process implemented in mechanical-biological treatment (MBT) plant generally based on mechanical and biological processes. The scope is to achieve the stabilization of the organic matter present in the solid waste (De Feo et al., 2012; Sirini et al., 2009).
The feeding is composed by unsorted municipal solid waste (UMSW) or the residual fraction from separate waste collection. Generally, in this condition the feeding cannot be used for the production of compost given the presence of other fractions in addition to the organic one. The mechanical treatment involves screening of all incoming waste in order to separate the different merchandise fractions. Usually, the mechanical section consists of (i) reception and storage, (ii) opening of the bags by means of "open-bag", (iii) screening and (iv) iron removal (De Feo et al., 2012; Godio et al., 2015; Sirini et al., 2009). Instead, biostabilization is aimed at (i) stabilizing the organic matter by means of the mineralization of the more easily degradable components with final production of water and carbon dioxide and stabilized material, (ii) sanitizing the waste by means of temperatures not lower than 55°C and (iii) reduce the volume and mass of the treated materials with weight loss of 20-30% due to evaporation (Arvanitoyannis and Ladas, 2008; Di Maria et al., 2014).

In terms of technological solutions, currently in Italy and Europe, it is possible to identify two types of MBT plant: (i) treatment separated flow, (ii) single-stream treatment (De Feo et al., 2012; Sirini et al., 2009). However, the main output of a bio-stabilization system is the SRF (Solid Recovered Fuel) characterized by high calorific value (Nasrullah et al., 2014a; 2014b). The state-of-the-art suggests the use of air for biological treatment of waste. In fact, air represents the suitable solution in the case of an ordinary functioning of the MBT plant (De Feo et al., 2012). However, some frequently emergencies such as the overload could suggest the need to reduce the times of the biological treatment in order to obtain a greater volume for the treatment of additional feeding.

In this context is held the collaboration between the Department of Civil, Environmental, Land, Building and Chemistry (DICATECh) of the Technical University of Bari, C.I.S.A. SpA, a leader in the field of waste management operating in Taranto (Apulia Region, Southern Italy) and SIAD SpA (Italian Society for acetylene and derivatives) of Bergamo. The intent is to provide and put into operation the first Italian prototype plant which uses pure oxygen to develop aerobic processes.

In details, the article deepens the main energy, engineering, environmental and process safety aspects of a pure oxygen-based full-scale bio-stabilization system treating UMSW. To best of our knowledge, just a few documented experiences are reported in the literature so as shown in Table 1.

2. Materials and methods

The activities were carried out at the Massafra MBT plant managed by CISA Spa and characterized by a treatment capacity of 220,000 tons/year. Table 2 and Fig. 1 show the main data and treatment phases of the MBT plant under investigation.

Considering the framework of the experimentation, the main steps were the following: (i) plant characterization and data input collection, (ii) assessment of energy consumption of all the equipment’s, (iii) integrated design of the pure oxygen system considering energy, engineering, environmental and process safety aspects.

For the first step, three operation cycles of the biocell shown in Fig. 2 have been considered.

3. Results and discussion

3.1. Analysis of the energy consumption of the conventional aeration system

Table 3 shows the results of the monitoring of the energy consumption with reference to the three cycles of functioning of a single biocell. Considering a contact time of 8 days, energy performance has been as follows: (i) biocell blower = 2352.13 kWh; (ii) biofilter
blower = 1280.69 kWh; (iii) sewage pump = 12.4 kWh; (iv) biofilter water pump = 39.3 kWh; (v) hot humidifier pump = 6.1 kWh.

The consumption estimation has been used to design the pure oxygen system as well as to represent the so-called “baseline scenario”. Results have shown how the blower of the tunnel (the aeration system visible in Fig. 1f) is the most energy-intensive machinery.

**Table 1.** Overview on the use of pure oxygen for the bio-stabilization of the organic fraction of municipal solid waste (OFMSW)(Source: SIAD)

<table>
<thead>
<tr>
<th>No</th>
<th>Country</th>
<th>Waste composition [%]</th>
<th>Heap Characteristics</th>
<th>Conventional aeration</th>
<th>Pure oxygen aeration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OFMSW</td>
<td>Wood</td>
<td>Contact time [days]</td>
<td>IRDp(a) [mgO₂/kgVS/h]</td>
</tr>
<tr>
<td>1</td>
<td>Piedmont Italy</td>
<td>60</td>
<td>40</td>
<td>15</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>Piedmont Italy</td>
<td>60</td>
<td>40</td>
<td>15</td>
<td>750</td>
</tr>
<tr>
<td>3</td>
<td>Lombardy Italy(b)</td>
<td>100</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Emilia-Romagna, Italy(c)</td>
<td>75</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(a): IRDp = respirometric Index; (b): Inlet IRDp value of 2800 mgO₂/kgVS/h; (c): The process was more efficient compared to conventional aeration and was completed in 5-6 days

**Table 2.** Main parameters of the MBT plant under investigation

<table>
<thead>
<tr>
<th>Main characteristics of the CISA Spa plant: Pre-selection and bio-stabilization; RDF production; Associated landfill</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entrance in operation</strong></td>
</tr>
<tr>
<td><strong>Days of conferral</strong></td>
</tr>
<tr>
<td><strong>Working days for the RDF production</strong></td>
</tr>
<tr>
<td><strong>Eligible quantities</strong></td>
</tr>
<tr>
<td><strong>Eligible CER codes</strong></td>
</tr>
</tbody>
</table>

3.2. Integrated design of the pure oxygen system

Fig. 3 shows the positioning and the main elements of the pure oxygen system. The storage (Fig. 3b, 3c) has the function to enter oxygen within the biocell by means of an atmospheric evaporator connected to the transport pipe.

In detail, the storage and the liquid oxygen vaporization section consists of a cryogenic container with a total capacity of 12,000 liters designed to store liquid pure oxygen
joined by a cold evaporator. The main characteristics of the liquid oxygen container are the following: volume = 12,000 liters; weigh = 13,692 kg; max operating pressure = 15 bar; operating pressure = 10 bar; design and construction are according to ISPESL/PED; safety devices according to Italian Law (DM, 1974).

Instead, the main characteristics of the air evaporator are as follows: max flow-rate = 310 Nm$^3$/h; heating fluid = air; model = VMP 310.

![Fig. 1. CISA Spa MBT plant under investigation: (a) Acceptance and weighing of waste; (b) Waste storage in the reception area; (c) Primary shredder; (d) Iron separator; (e) Biocell; (f) Nozzles for blowing air on the floor; (g) Primary air pipe; (h) Biofilter](image)

3.3. Identification of the main engineering, management, environmental and safety aspects

The design of the system described in the previous paragraph considered several aspects discussed below. From the engineering point of view, the system has been installed outdoors and on a base of concrete suitable to support the loads induced by the weight of the equipment and overload caused by wind, snow, seismic actions. The existing legislation has
required a 40 cm thickness of the base and an elevation of about 10 cm above the existing forecourt. The base has a surface area of 23.76 m² (4.40m x 5.40 m). The plant area is surrounded by a bead in concrete with a thickness of 20 cm and 50 cm height. The bead has the purpose of protecting the equipment from possible impacts of vehicles in consequence of false maneuvers. On that bead, in order to prevent access to the system by unauthorized persons, a metal mesh fence has been realized using steel pallets with a height of 2.00 m.

![Fig. 2. Details of the biocell (a) and the blower (b) of the CISA Spa plant](image)

**Table 3.** Results of the energy consumption monitoring with reference to the bio-stabilization process equipment

<table>
<thead>
<tr>
<th>Treatment cycles</th>
<th>Equipment</th>
<th>Blower of the tunnel [kWh]</th>
<th>Blower of the biofilter basin [kWh]</th>
<th>Pump into the wastewater basin [kWh]</th>
<th>Pump into the filtered water basin [kWh]</th>
<th>Pump into the dehumidifier basin [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycle 1: from 23/11/15 to 01/12/15</td>
<td>2290.29</td>
<td>1325.47</td>
<td>12.50</td>
<td>39.94</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>Cycle 2: from 05/11/15 to 13/12/15</td>
<td>2493.10</td>
<td>1235.90</td>
<td>12.06</td>
<td>40.51</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>Cycle 3: from 06/01/16 to 14/01/16</td>
<td>2272.99</td>
<td>1865.54</td>
<td>11.57</td>
<td>37.54</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>Average values</td>
<td>2352.13</td>
<td>1280.69</td>
<td>12.04</td>
<td>39.33</td>
<td>1.06</td>
<td></td>
</tr>
</tbody>
</table>

The plant area is dedicated exclusively to the pure oxygen system and any storage of flammable materials and/or fuels were placed at distances greater than those provided by the Italian Law (Circular, 1964). In this regard, Fig. 3d shows how the distances provided for different categories of buildings and structures were respected.

Additional results involved the identification of the main design aspects such as (i) the safety valve on the container-dispenser cryogenic liquid oxygen, (ii) the reducer/pressure stabilizer also in the container-dispenser, (iii) the control and regulation instrumentation for pure oxygen flow and (iv) the system for the monitoring of the main pollutants parameters.
Fig. 3. Elements of the pure oxygen system installed at the biological section of the CISA Spa plant: (a) Location and (b-c) details of the storage and oxygen vaporization system; d) Safety distances (3 m; 7.5 m; 15 m)

Additionally, the installation of two pneumatic valves on the oxygen piping, internal to the biocell, was a necessary condition. The maximum speed of oxygen, under operating conditions, will have to be $\leq 4$ m/s.
4. Concluding remarks

The experience conducted at the MBT plant of Massafra allowed identifying the key aspects for the safe design of a pure oxygen system. The design is to be considered “integrated” as several aspects such as energy, engineering, environmental and process safety should be taken into account.

Once the pure oxygen system is put into operation, the experimentation helps to identify the main process parameters useful also for an economic assessment of this unconventional system investigated.

Acknowledgements
The authors gratefully acknowledge engineers Danila Lo Bianco and Lucia Vinci for the valuable work done at CISA Spa.

References

Di Maria F., Micale C., Morettini E., (2014), Alternative residual municipal solid waste management scenarios in areas with deficiency or absence of incinerators, Procedia Environmental Science, Engineering and Management, 1, 7-11.