
Copyright:
© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/3.0/

DOI link to article:
https://doi.org/10.1016/j.egypro.2014.11.949

Date deposited:
22/12/2017
Techno-economic Analysis of BioChar Production and Energy Generation from Poultry Litter Waste

Y. Huang[a]*, M. Anderson[a], G. A. Lyons[b], W. C. McRoberts[b]
Yaodong Wang[c], D.R. McIlveen-Wright[a], AP Roskilly[c] and N.J. Hewitt[a]

[a]Centre for Sustainable Technologies, School of the Built Environment University of Ulster, Jordanstown, BT37 0QB, UK
[b]Plant Health and Environmental Protection and Food Chemistry Branch, Agri-Food and Biosciences Institute for Northern Ireland, Newforge Lane, Belfast, BT9 5PX, UK
[c] The Sir Joseph Swan Centre for Energy Research, Newcastle Institute for Research on Sustainability, Newcastle University, Newcastle Upon Tyne, NE1 7RU, UK

Abstract

The technical, environmental and economic analysis of generating electricity and/or heat together with bio-char from poultry litter (PL) waste is the subject of this study. For this analysis, the process simulation software ECLIPSE is used. Modelling and simulation have been conducted over the configuration: combined updraft gasification and pyrolysis process integrated with an Organic Rankine Cycle (ORC). The facility will initially be capable of processing 1500kg of PL waste at 30% moisture content every hour. The expansion plans of the facility are underway to deal with 3000kg of PL waste per hour. Based on the results achieved, the key technical and environmental issues have been examined. Finally, an economic evaluation of the system is performed. The ECLIPSE simulation shows that the yield of biochar produced in the updraft gasifier is around 415kg per hour and the producer gas is about 2052m³/hour with a calorific value of 4.45MJ/Nm³. Gross electric power generated by the ORC system is 391kWh. Recovered low grade heat for space heating is estimated at 1822kWh.

The results of the economic analysis demonstrate that if the plant is paying 10£/tonne for receiving and handling the PL waste without the options of selling either heat or electricity, the Breakeven Cost for the biochar from the selected system is estimated at £215 per tonne. If the sales of electricity and heat produced by the system are assumed to be about 60£/MWhe and 10£/MWhth, this value will go down to £176 per tonne. The case studies also indicate that if a gate fee of £20/tonne is introduced, the biochar cost (with CHP installation) can be reduced from £176 to £104 per tonne, accounting for 40% cost reduction. On the other hand if biochar generated has an average price of £150 per tonne in the market, the plant is still paying a handling fee of 10£/tonne for the PL feedstock but will receive one Renewable Obligation Certificate (ROC) from the UK Government, the Levelised Cost of Electricity for the power generation will be 51£/MWhe, which is compatible with electricity generated by fossil fuel power plants.

* Corresponding author. Tel.: +0-2890368483.
E-mail address: y.huang@ulster.ac.uk.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the Organizing Committee of ICAE2014

Keywords: techno-economic analysis, modelling and simulation, poultry litter, bio-char, updraft gasifier.

doi:10.1016/j.egypro.2014.11.949
1. Introduction

The broiler poultry production in Northern Ireland, UK is one of important industries which have a significant impact on the local economy [1]. Concentrated poultry farms, however, generate large quantities of poultry litter (PL) waste, resulting in problems for management and disposal. Excessive land application of non-appropriate treatment poultry litter is not environmentally and socially acceptable as its contaminating regional watersheds. With stricter environmental legislation coming into effect in EU countries, the incineration/direct combustion of poultry litter is tightly controlled in order to limit harmful emissions of VOCs and dioxins. To decrease PL waste and mitigate climate change it is urgent for us to develop green, cost-effective and sustainable solutions to deal with the increasing quantities of poultry litter. Common poultry litter consists of a mixture of wood shavings, sawdust and straw, together with the spilled feed and accumulated droppings. As an agricultural biomass derived waste stream, poultry litter yielded can be used as a source of renewable energy for local poultry farms via the pyrolysis, gasification and combustion processes. The by-product (bio-char) can also be used as a soil amendment which boosts soil fertility [2].

The overall objective of this paper is to perform a comparative techno-economic assessment of the small-scale integrated gasification of poultry litter to give rise to both energy and bio-char products. To achieve these objectives, the work begins with an investigation of the property of poultry litter as a gasification feedstock using the information obtained from experiments. An integrated pyrolysis/updraft gasifier and Organic Rankine Cycle (ORC) are then selected and process diagrams are created. The process modelling and simulation are done using the ECLIPSE process simulation package [3]. Based on the results of mass-energy balances, an economic analysis of the options is then carried out together with a sensitivity study.

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>as received</td>
</tr>
<tr>
<td>CV</td>
<td>calorific value</td>
</tr>
<tr>
<td>DAF</td>
<td>dry and ash free</td>
</tr>
<tr>
<td>ORC</td>
<td>organic Rankine cycle</td>
</tr>
<tr>
<td>PL</td>
<td>poultry litter</td>
</tr>
<tr>
<td>ROC</td>
<td>renewable obligation certificate</td>
</tr>
</tbody>
</table>

2. Materials and Methods

2.1 Feedstock analysis

The feedstock properties are important in the selection of the poultry waste conversion process. The laboratory results of poultry litter used in this study are shown in Table 1. On an as received (AR) basis the proximate analysis shows that the poultry litter contains 29.96% moisture, 22.38% ash, 41.28% volatile matter and 6.38% fixed carbon. The gross calorific value (CV) is estimated at around 18.64MJ/kg on dry and ash free (DAF) basis. Although this CV lies below most fossil fuels (~35MJ/kg) it is compatible with most biomasses (~20MJ/kg) [4].

Table 1. Poultry litter analysis

<table>
<thead>
<tr>
<th>Proximate analysis (% w/w ar)</th>
<th>Moisture</th>
<th>Ash</th>
<th>Fixed carbon</th>
<th>Volatile</th>
<th>CV (MJ/kg ar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.96</td>
<td>22.38</td>
<td>6.38</td>
<td>41.28</td>
<td>8.88</td>
<td></td>
</tr>
<tr>
<td>Ultimate analysis (% w/w daf)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>50.82</td>
<td>6.23</td>
<td>31.68</td>
<td>7.97</td>
<td>18.63</td>
</tr>
</tbody>
</table>

2.2 Process description
A schematic presentation of the proposed bio-char production and energy generation system is shown in Fig. 1. The thermal conversion process consists of an updraft gasifier connected to an integrated pyrolysis process. The work process is as follows: poultry litter is delivered with the moisture content approximately 30% to the pyrolysis area through an auger system. As an intermediate moisture level, it is probably not worth including a dryer in the process. Poultry litter feedstock is then undergone the thermal decomposition at temperature of 800°C. The remaining solid contents are gasified into producer gas in the updraft gasifier. The producer gas is burnt in a thermal oxidiser and the majority of heat generated is recovered for operating the ORC system [5].

![Schematic Diagram of Pyrolysis/Updraft Gasifier and ORC Processes](image)

3. Results and Discussion

The proposed plant is modelled and simulated using the ECLIPSE process simulation package, including the pyrolysis process, the updraft gasifier, the ORC process and the integration of the whole system. The ECLIPSE simulation shows that when the PL feedstock is set to 1500kg/hour, the yield of biochar produced is around 415kg per hour. The updraft gasifier generates 2050m³/hour producer gas, which contains a CV of 4.45MJ/Nm³. If the ORC system is installed, the electricity generated is 405kWhe(Gross). The total available waste heat recovered is 1822kWh th, resulting in a relatively lower heat to electrical power ratio of 4.5. Carbon dioxide emissions are found to be 2.8kg/kWhe. This level of CO₂ emissions is high, due to its low electrical efficiency. Taking into account of all the heat recovered, however, CO₂ emissions can be decreased to 0.45kg/kWh.

Since economic simulation results are too detailed to be shown here, certain indicators, as illustrated in Table 2, have been selected. The economic indicators for Case Study 1 show that the minimum capital investment is given at £1,991,500 including the equipment of emission controls and 15% of owners’ cost. The relatively high cost is mainly due to the small size of the plant. The breakeven cost for the biochar produced is £215 per tonne when the feedstock cost of 10£/tonne is assumed. If a gate fees of 20£/tonne is introduced the breakeven biochar cost is lowered from £215 to £143 per tonne. Furthermore if carbon credits of £10 per tonne of CO₂ are considered the biochar cost can be £134 per tonne, giving a reduction of 6%. The capital costs for Case Study 2 are given at £3,265,500. If electricity can be sold back to the grid at 60£/MWh and heat recovered is utilised at 10£/MWh, the breakeven cost for the biochar is estimated at £176 per tonne. If a gate fee of £20 per tonne poultry litter is made the biochar cost can be reduced from £176 to £104 per tonne, accounting for 40% cost reduction. If carbon credits of £10 per tonne of CO₂ are included the biochar cost can be £96 per tonne, giving a further reduction of 7%. On the
other hand if biochar produced has an average price of £150 per tonne in the market, the plant is still paying a handling fee of 10£/tonne for the PL feedstock but will receive one Renewable Obligation Certificate (ROC) from the UK Government, the Levelised Cost of Electricity for the power generation will be 51£/MWh, which is compatible with electricity generated by fossil fuel power plants.

<table>
<thead>
<tr>
<th>Table 2, Economic analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case Study 1</strong>: Basic process capital costs, £ (incl. updraft gasifier, emission control cost and +15% owners’ cost)</td>
</tr>
<tr>
<td><strong>Case Study 2</strong>: Total process capital costs including an installed cost of the ORC unit (400kWe), £</td>
</tr>
<tr>
<td>LCOE, £/MWh (with the biochar price of 150£/tonne, feedstock charges of 10£/tonne and one ROC)</td>
</tr>
</tbody>
</table>

4. Conclusion

A number of scenarios have been modelled and simulated to assess the technical and economic viability of the production of bio-char. From the results and discussion, the following points can be concluded:

It is technically and economically feasible to use PL as the feedstock to operate a pyrolysis/gasification process. The mass and energy balance results indicate that the heat produced in the gasification process can properly cope with heat demands from the whole system. Due to near-zero CO2 emissions, the PL waste fuelled CHP installation offers a significant CO2 saving opportunity for the farm energy supplies. If a large amount of excess heat from the bio-char production process is utilised this will reduce heating fuel consumption greatly. As bio-char has the potential to be sold as a soil improver, at a commercial level income from the proposed process to offset relatively high capital costs is realised from both the sale of energy and the sale of bio-char. The ‘biochar only’ option has a higher cost than the ‘biochar and CHP’ option. It is clear from Table 2 that the biochar price, gate fees and ROCs have a significant impact on the LCOE when CHP installed.

Acknowledgements

This research outcome is from the SBRI Competition ‘Sustainable Utilisation of Poultry Litter’ funded by Invest Northern Ireland, the Northern Ireland Department of Agriculture and Rural Development and the Northern Ireland Department of Enterprise Trade and Investment.

References


Biography

Dr Ye Huang is a versatile and successful researcher and developer within energy system modelling and energy conversion systems. He has over 25 years of experience in techno-economic analysis of fossil fuels and biomass/waste utilisation, systems development and environmental research.