Hydrothermal Carbonization and Gasification Technology for Electricity Production using Biomass

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Abstract

The concept uses agricultural residues as rice husk and rice straw as a renewable energy resource. These rice residues typically exhibit low energy density which limits an economic transportation for electrical power generation. In addition usually combustion does not make sense due to the transportation restrictions and the high contents of ash and dust. To master this challenge, the process of hydrothermal carbonization (HTC) is applied to produce bio coal as a transportable value added product with high energy density and the same caloric value as lignite. The produced bio coal can be transported to gasification units in remote villages to generate electrical base load power for mini-grids in rural communities. Furthermore the usage of the bio coal for gasification has the advantage of a clean gasification process with a very low level of ash and dust pollution. This approach could be the key to a profitable generation of electricity as the HTC carbonization facility produces enough bio coal to achieve economic efficiency while supplying remote gasification units to produce electricity for mini-grids on a reliable and steady level.

Keywords: Rural electrification; biomass; hydrothermal carbonization; gasification; mini-grids

1. Introduction

Rice grows in many regions of Asia with an average yield of 3.5 tons/ha. The by-products are rice husk, which accounts for 20\% by weight of the rice, and rice straw. These rice residues account for almost 2.5 tons/ha on average. Especially countries such as the Philippines, Thailand, Vietnam and Myanmar are well endowed with renewable energy resources based on these by-products of rice. Based on the Philippines’ the annual rice production amounts to 18.5 mio tons in 2013, about 9 mio tons of straw

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accrue. Assuming a calorific value of 4 kWh/kg or 4 MWh/t, and a conversion efficiency of 30%, this sums up to potentially 11 mio. MWh electrical energy corresponding to an installed power capacity of 1.8 GW.

For the time being rice husk is used in widespread applications. Besides animal feeding, it is used as fuel for heating purposes in smaller enterprises (Fig. 1) or for gasification units to generate electricity in decentralized mini-grids [1] and the Indian company Husk Power Systems (www.huskpowersystems.com). These outcomes show a promising opportunity in employing rice husk as a renewable energy resource. Meanwhile there is a functioning fuel market for rice husks in many countries of Asia (e.g. Philippines: 1.15 Phil. Pesos per kg (2013), Fig. 1(b)).

![Fig. 1. (a) Usage of rice husk for heating purposes in a small manufacturing enterprise [2], (b) Rice husk delivery [2]](image)

A market for rice straw has not been established due to the difficulties in processing like cutting and the high moisture content. Therefore a large amount of rice straw is burned or dumped in the fields resulting in waste disposal challenges and methane emissions [3]. In the Philippines for example, 60% of the rice straw is burned in the fields and remains energetically unused. That means that there is a large potential to use rice straw as a renewable energy resource. Many attempts have been made in the past to use rice straw as a resource to generate electricity in an effective, economic and environmentally friendly way. For the time being, however, it is challenging to find a sound possibility. Direct combustion is generally hazardous to the environment and human health due to the non-avoidable large amounts of ash and dust as well as the needed energy to pre-dry the biomass. Fermentation is not applicable due to the high content of cellulose. Direct gasification of rice residues, especially rice straw, typically fails due to the low melting temperature of the ash [4].

As a result, carbonization of rice straw seems to be the only viable alternative. But the capital-intensive process of carbonization with the aim to produce briquettes or charcoal with a high calorific value and use it later as an alternative to the direct combustion is typically connected to prohibitively high transportation costs and subsequent storage costs [5]. Lacking an integrated concept uniting logistics, production,
marketing and strategy planning comes especially into play as the produced synthetic charcoal can only substitute similar products with a limited application mainly for heating purposes on a local range and in small scale. Thus producing charcoal or briquettes through a conventional small scale carbonization process provides typically disappointing results in terms of high complexity and high inefficiency. Consequently most of the applied carbonization procedures failed or were not appreciated by the users, see Fig 2.

The failure of all these attempts so far does not necessarily mean that this way routes to the wrong direction. Putting together, it makes sense to think about possibilities to integrate optimized methods to achieve a higher quality of the fuel. The key is to combine a carbonization technology with a gasification unit to overcome the bottlenecks of the single technologies. To develop a sound business model based on carbonization, it is necessary to achieve an end-product with the properties of at least lignite quality which can be used in large scale deployment for gasification. Thus, the rice residues are converted into a useful form of energy to meet the thermal and mechanical energy requirements of power engines based on gasification.

2. Biomass processing by hydrothermal carbonization (HTC)

Many conventional carbonization projects suffer from suboptimal target setting. The typical aim is to produce a synthetic charcoal on a small “household” scale to replace the original material, i.e. rice husk or rice straw, rather than generate a valuable large scale product with high energy density to replace fossil fuels. One practical conclusion is to improve the carbonization process aiming at a “better charcoal” with the properties and the quality of at least lignite. Such an improved carbonization process provides a high energy product to reduce the transportation costs per energy unit and enables rural people to generate additional income by selling this product as a high-quality fuel source either to anchor business customers like the operators of the gasification units (energy suppliers) or to a retailer that supplies households with bio coal primarily substituting wood fires of the rural population. Under a long term customer development perspective, this can be very appealing. Rural population without access to electricity become familiar with the advantages of the bio coal and therefore more open minded towards the utilization of electricity from that energy source. With an adequate campaign, this approach could be very promising to increase the private customer base. Once the awareness for the biocool’s advantages like the
possibility of providing electricity as well as heat for cooking to substitute smoking wood fires has reached the villagers minds, the product’s market readiness will be achieved.

The HTC conversion provides the following value-added features compared to conventional biomass gasification:

- The efficiency of this carbonization process is 66% according to practical experience undertaken so far.
- The density is increased considerably. Rice straw as a raw material has a low density of 120 kg/m³, whereas, after the HTC carbonization the density increases to 850 kg/m³. The higher density ensures easier handling, storing and transportability.
- Basically any biomass material can be converted into bio coal and nutrient water as by-product within a few hours. The wet biomass material is compressed and heated in a reactor under high pressure of 20 bar and temperatures of 200 degrees (Fig. 3). Synthetic bio coal with the quality of lignite is generated after 5-12 hours.
- The HTC technology can be applied to dry as well wet biomass. Thus the energy intensive drying process of all other carbonization procedures is not necessary. Certain humidity is even desired to comply the process requirements. That is a very advantageous feature compared to other carbonization methods. Usually wet biomass is challenging to carbonize due to the high moisture content in the cellular structure affecting this process negatively.

The end product of the HTC procedure is a liquid suspension containing the bio coal particles. The remaining humidity is easy to press out mechanically. Further the excessive energy caused by the exothermal process is used to dry the bio lignite to a humidity level of about 10% which is suitable for gasification purposes.

Fig. 3. HTC&G carbonization scheme
Currently the HTC technology is provided by following two German companies:
- CS Carbon Solutions GmbH, Kleinmachnow
- Grenol GmbH, Ratingen

Carbon Solutions (CS) operates a pilot site in Teltow with a capacity of processing 10,000 tons wet biomass per year. According to a company statement the plant works reliably on a continuing basis to convert greenery of the public parks of the city of Berlin. Their experience has shown that a minimum size of 3,000 tons per year should be planned for a HTC site in order to maintain a reliable process and high product quality. Common agreement is that these sites can operate economically if there are no material costs for biomass. This is typically the case for biomass residues such as leaves or grass in parks. The city of Berlin conducted an analytical study in which the HTC technology performs best compared to other procedures, i.e. fermentation or composting [6].

3. The HTC&G concept - Integration of the HTC technology with gasification units

Due to its key features – usage of wet biomass and generation of a high-value end product on a large scale - the HTC-carbonization of rice residues and gasification of the produced synthetic bio coal is considered for an integrated approach. This HTC&G concept consists of two components:
- On a first stage synthetic bio coal is produced by the hydrothermal carbonization process (HTC technology) in a site with a capacity of 4,000 tons per year to achieve a competitive product with high energy density.
- On a second stage the produced synthetic bio coal is used as a fuel in gasification units located in villages alongside to the HTC facility to produce electricity.

Fig. 4: The HTC&G concept for rice residues

In such a way the quality of the rice residues as a renewable energy resource is improved to meet the demand of gasification units for rural electrification purposes. This is the core idea of the proposed two-stage approach (Fig. 4). Rice residues transportation is done on the conventional way to supply one HTC carbonization unit. The transportation costs of the produced bio coal to villages for gasification purposes are significantly lower due to the higher density of the produced bio coal. Along with that goes a clear
reduction of dust pollution and fuel oil consumption in comparison to a direct rice straw combustion, as it is already done, e.g. the Roi-et Green power plant located in the north-eastern part of Thailand [7]. In addition the HTC&G concept incorporates the requirement of scalability from the beginning on. This leads to a scalable model which can be replicated in several villages. Furthermore it provides the flexibility to balance out changing demand for electricity. By this it is possible to avoid excessive costs due to over or under-capacities. So, a living business model based on dynamic production is created. “One of the key requirements for the implementation of a scalable model is a low cost but capable management team on the ground which is committed to the power supply business and covers all areas of expertise required like technological, business management and financial as well as sociological know-how.” [8]. In the case of rice husk a robust technology fulfills these requirements, as the Indian company husk power systems shows with its holistic franchise approach. One of the most important success criteria of those mini grids is the capability to provide baseload electricity to a price comparable to national grids. Given this, the technology is accepted by the rural population and local enterprises with a stable demand for electricity can be attracted or founded. This impact works in both ways as mini-grids can only operate profitably if economy of scale effects can be gained locally. This means that the increase of demand for electricity has to be fostered by supporting local enterprises. Once initiated, successful business ideas will lead to an improved local income situation that in the next step leads to increased demand for energy consumption.

4. Business valuation

The economic rationale depends largely on regional conditions. As an example the business valuation is conducted in the case of the Philippines with following assumptions (Table 1):

- Total investment costs for the HTC&G facility with a capacity of 4,000 tons of rice residues yearly (16 tons daily) account for USD 1.5 mln, whereas HTC capital requirement amounts to USD 0.9 mln. according to the German company Grenol based on their own experience. The investment costs for the gasification sites of USD 0.6 mln are given by the power price for a conventional gasifier of roughly 2000 USD/kW.
- Yield of 350 tons rice and 250 tons rice residues per km2.
- Material costs for rice husk of 1.15 Phil Peso/kg (3 USD-ct/kg).
- Transportation costs for rice residues of 6 USD per ton.
- Labour costs of 14 USD (700 peso) daily for one worker in the HTC site. The required work force is assumed to be three for the HTC site and two workers for each of the assumed six decentralized gasification units.
- Transportation costs for the produced bio coal of 1 USD per km by assuming an average distance of 25 km from the HTC site to the gasification units on average and 8 tons vehicle transport.

Taken together the HTC converts 4,000 tons of rice residues into roughly 800 tons synthetic bio coal. The conversion increases the caloric value by 70%. Gasification of the produced synthetic bio coal generates 1.7 GWh electrical energy per year based on six power stations of 50 kW each assuming 6,000 hours of usage per year and an efficiency rate of 35%. The assumptions lead to total costs of roughly 280,000 USD, whereas depreciation over 20 years amounts to 74,000 USD yearly.

Of specific importance are the levelized costs of electricity (LCOE) split into operating expenditure (OPEX) costs and capacity expenditure (CAPEX) costs. Based on a lifetime of 20 years and a discount rate of 10% the LCOE amounts to 0.22 USD/kWh whereas CAPEX costs are 0.10 USD/kWh and OPEX costs 0.12 USD/kWh. This result makes clear, that the proposed technology provides significant cost advantages compared to widely used Diesel Gensets with a LCOE of 0.35 USD/kWh in the case of the Philippines [9]. Furthermore the technology is highly competitive from the beginning on as the LCOE of
0.22 USD/kWh is comparable to the electricity tariff of national grids. Based on this LCOE the annual revenues would account for roughly 380,000 USD and a sound profitability in terms of an EBIT of 100,000 USD corresponding to a return of investment (ROI) of 7% could be achieved.

Table 1: Business assessment: Rice straw carbonization by the HTC&G technology

<table>
<thead>
<tr>
<th>Business assessment</th>
<th>HTC&amp;G site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs HTC site Mio. USD</td>
<td>0.9</td>
</tr>
<tr>
<td>Investment costs Mio. gasification units Mio. USD 2,000 USD/kW</td>
<td>0.6</td>
</tr>
<tr>
<td>Total Investment (Mio. USD)</td>
<td>1.5</td>
</tr>
<tr>
<td>Capacity HTC site rice residues ton/ p.a.</td>
<td>4,000</td>
</tr>
<tr>
<td>Caloric value rice residues (kWh/kg)</td>
<td>3.6</td>
</tr>
<tr>
<td>Efficiency HTC procedure</td>
<td>34%</td>
</tr>
<tr>
<td>Produced bio coal ton/p.a.</td>
<td>800</td>
</tr>
<tr>
<td>Caloric value bio coal (synthetic lignite) (kWh/kg)</td>
<td>6.1</td>
</tr>
<tr>
<td>Efficiency gasification</td>
<td>35%</td>
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<tr>
<td>Material costs rice residues USD p.a.</td>
<td>113,000</td>
</tr>
<tr>
<td>Labour costs USD p.a.</td>
<td>61,000</td>
</tr>
<tr>
<td>Transportation costs rice residues USD p.a.</td>
<td>24,000</td>
</tr>
<tr>
<td>Storage &amp; Transportation costs bio coal USD p.a.</td>
<td>10,000</td>
</tr>
<tr>
<td>Total OPEX costs USD p.a.</td>
<td>206,000</td>
</tr>
<tr>
<td>Depreciation per year USD</td>
<td>74,000</td>
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<tr>
<td>Electricity output GWh per year</td>
<td>1.7</td>
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<tr>
<td>CAPEX USD-ct/kWh</td>
<td>10</td>
</tr>
<tr>
<td>OPEX USD-ct/kWh</td>
<td>12</td>
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<tr>
<td>LCOE total USD-ct/kWh</td>
<td>22</td>
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<tr>
<td>Revenues per year USD @ LCOE</td>
<td>380,000</td>
</tr>
<tr>
<td>Earnings per year USD (EBIT)</td>
<td>100,000</td>
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</table>

Thus the HTC&G concept is attractive from an economical perspective. The concept, however, should not only be considered by analyzing costs and earnings. This concept requires a more holistic assessment of the quality of energy supply delivered as it achieves long term sustainability in two other dimensions:

- Ecological sustainability: From a climate approach the substitution of 1.7 GWh electricity p.a. avoids a CO2-emission of 1300 tons CO2 yearly if hard coal is used to generate electricity in a power plant with 37% efficiency and corresponding CO2 emissions of 750 g CO2 per 1 kWh produced electrical energy.

- Social sustainability: The two-stage concept of rice residues carbonization by the HTC&G technology requires an area of roughly 16 km² for each HTC site. This is equivalent to a circle of only 2.3 km radius underlying the concept of a local network in a rural area. Thus every HTC site is able to create employment in rural areas, not only by the assumed work force of 15 persons for logistics and maintenance purposes but rather more in a considerable size to support entrepreneurship based on productive use of the electricity generated.
5. Conclusion

This paper introduces a concept to use rice residues for electrical power generation by applying the hydrothermal carbonization technology combined with gasification units (HTC&G concept). The proposed two-step approach takes into account the dispersed availability of biomass and its low energy density as well as the necessity of an economic generation of electricity. The HTC&G concept makes it possible to replace fossil resources of energy economically without subsidies. Unused biomass like rice straw can be used effectively and environmentally friendly. In addition this technology should be recognized as having a far greater potential impact on energy access and economic activity, especially as it is also capable of providing high quality, surplus supply as opposed to simply substituting the local supply by briquetting or conventional carbonization procedures. Furthermore applying the HTC&G concept on a local level avoids negative environmental effects in terms of transportation efforts and dust pollution of a large scale carbonization. Finally and most remarkable employment for rural people is created. Accordingly there is social and economic benefit using this concept for countries such as Bangladesh, India, Indonesia, Myanmar, the Philippines, Thailand and Vietnam.

References