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Intermediate pyrolysis: A sustainable biomass-to-energy concept – Biothermal valorisation of biomass (BtVB) process

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Wastewater treatment coupled with energy crop cultivation provides an attractive source of cheap feedstock. This study reviews an advanced, closed-loop bioenergy conversion process [biothermal valorisation of biomass (BtVB)], in which pyroformer is coupled to a gasifier. BtVB process was developed at European Bioenergy Research Institute (EBRI), Aston University, UK and demonstrates an improved method for thermal conversion of ash-rich biomass.

Keywords: BtVB process, CO_2 sequestration, Green energy production, Intermediate pyrolysis, Technology development

Introduction

Effluent irrigated short rotation energy crops provide a solution for wood scarcity in India where fuelwood requirement is increasing with population growth[1]. To satisfy increasing energy demand, however, requires both enhanced biomass production and effective energy conversion technology, combined with an optimised land use to reduce competition with agricultural food production. Biomass obtained from effluent irrigation is an excellent feedstock for energy purposes that avoids competition for land or freshwater usage[2]. Compared to combustion, pyrolysis provides better energy conversion as reactions are under controlled conditions with a wide range of products suitable for different applications. European Bioenergy Research Institute (EBRI), Aston University, UK has developed an intermediate pyrolysis [biothermal valorisation of biomass (BtVB)] process with reaction conditions preventing formation of high molecular tars and offering dry char suitable for different applications like combustion, carbon sequestration and soil refertilisation. Combined pyrolysis-gasification system[3,4] is insensitive to feedstock quality and is advantageous for developing countries where increasing energy demand is coupled with scarcity of agricultural land or wood.

Biomass use as an energy resource as well as chemical resource has significant economic and ecological impacts. Besides, classical use of wood and straw, agricultural biogenic wastes are of high interest[5]. To minimise competition with food production, focus is on biomass waste streams and biomass grown on brownfields not suitable for agriculture. Other important aspect for future bioenergy industry is to offer closed loops in terms of fertiliser recycling. Within the next 30-50 years, a shortage of fertiliser, especially of phosphorous (P), is expected; in addition, production of nitrogen (N) based fertiliser is highly energy intensive and therefore contributes to climate change[6,7]. Further, challenging routes are reuse of produced carbon dioxide (CO_2) within the whole concept of BtVB process as well as the use of solid byproduct, pyrolysis char as a soil conditioner (tera preta) and an additional medium to take up and store wastewater contaminants providing leaching to groundwater.

Wastewater treatment sites in India are excellent locations to combine advantages of bioenergy generation, offering solutions for soil remediation (phytoremediation) while not competing with agricultural food production. The plants of short-rotation plantations are supposed to take up contaminants (mostly hetero-organic compounds) and thereby clean wastewater to some extent[8,9]. Remaining contaminants are brought into the soil, where natural filtration process of the soil takes place[10].

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Vegetation is enriched by organic contaminants during phytoremediation process. These contaminated short rotation crops are ideal resources for bioenergy generation.

This review presents an advanced, closed-loop bioenergy conversion process, BtVB process, in which pyroformer is coupled to a gasifier.

Pyrolysis of Biomass

Pyrolysis of biomass increases specific energy density of intermediates to be applied for gasification or combustion; it is especially appropriate if transportation is required[9]. Until today, it has been difficult to use pyrolysis liquids as direct fuel for engines, though it has been partly achieved by Pytec for wood feedstock[11], which involves direct transfer of pyrolysis vapours into syngas via gasification. Fast pyrolysis converts biomass into maximum amount of liquid and minimum amount of gases for feedstocks like wood and is usually leading to one phase liquids high in water, acids and tars. In terms of other feedstocks (straws, grasses or industrial residues) from agricultural products like husks, the picture is much different[12]. Intermediate pyrolysis[3,4] generates high quality and highly energetic, dust and tar free pyrolysis vapours for combined heat and power (CHP) use after a gasification step.

Biothermal Valorisation of Biomass (BtVB) Process

Intermediate pyrolysis offers working conditions preventing formation of high molecular tars and offers dry and brittle chars suitable for fertilisation or combustion. In this type of processing, larger sized feedstock may be used without milling. This offers the opportunity to separate char from vapours easily and to operate a coupled gasifier with low ash, independent of ash content of the material before pyrolysis. Within BtVB process, energy (70%) of raw material is transferred into electric power and heat with high yield of electricity. BtVB process offers new options for usage of pyrolysis char, acting as a real source for carbon sequestration and in addition closing fertiliser loop. It offers a heat sink for and partly reuses produced CO_2 generating a CO_2 negative bioenergy process.

BtVB process converts biomass (low in oil), and ash-rich agricultural and forestry residues to produce heat and power. Intermediate pyrolysis accepts a wide variety of feedstocks (algae, residues from biogas plants, energy grass, wood residues and other residues from agriculture and forestry) and produces pyrolysis liquids (40-60%), char (15-25%), and gases (non condensable vapours, 20-30%). Pyrolysis vapours (60-75% of energy) are directly passed to a gasifier to power a gas engine[13,14]. Pyrolysis char (ash contained) is not gasified. Aqueous phase is added as a fertilizer to algae plantation. Concurrent reaction water is brought back to the system, so that water loop is closed. Pyrolysis char is partly taken to the energy grass fields as fertilizer - so called black earth. This black earth concept is the only way bringing carbon back to the soil and achieving a biological sequestration. Other part of pyrolysis char is eluted with water to extract the fertiliser, which is taken back to algae plantation. Residue of extraction (mostly ash free char) is dried and cofired/gasified or taken to fields.

Exhausts (CO_2, NO_x and. SO_2) of gas engine are taken to algae plantation as fertilizer. No CO_2 is set free; as besides algae other biomass will be pyrolysed, gasifed and converted to electric power, more CO_2 will be brought into algae plantation than CO_2 is created via converting process of algae to power, because the char is kept. Thus main delivery of biomass is from algae plantation. Biomass generation is done via photosynthesis at 20-25°C. For biomass, algae could be used with high oil content which will be squeezed before pyrolysis and the obtained oil can be used as biofuel or raw material for chemical industry. Another alternative is to use algae producing a maximum of biomass, which can be pyrolysed directly[13]. Fig. 1 shows whole integrated BtVB process. Additional feedstock for pyrolysis are regional feedstocks as wood residues, grass of different kind, residues of biogas plants as well Hungarian energy grass. Neither imported wood nor plants being competitors to food production processes will be used.

Black Earth and Fertilizer

Pyrolysis char (partial leached or not leached) mixed with sand or soil is called black earth. Terra Preta as black earth in South America is delivering best yields in food production since generations[15]. Industrial agriculture has a high demand of fertilizer and is therefore affecting the quality of soil negatively. For sustainable biomass to energy concepts, recirculation of minerals to the soil is essential. Black earth (pyrolysis char, 70%; and mineral components, 30%) concept represents in this context a closed system. Using black earth, recirculation of minerals into the soil is assured as mineral components remain nearly almost in the char after pyrolysis and hence fertilizer cycle is closed and sustainability is guaranteed. Pyrolysis char possesses high water holding capacity

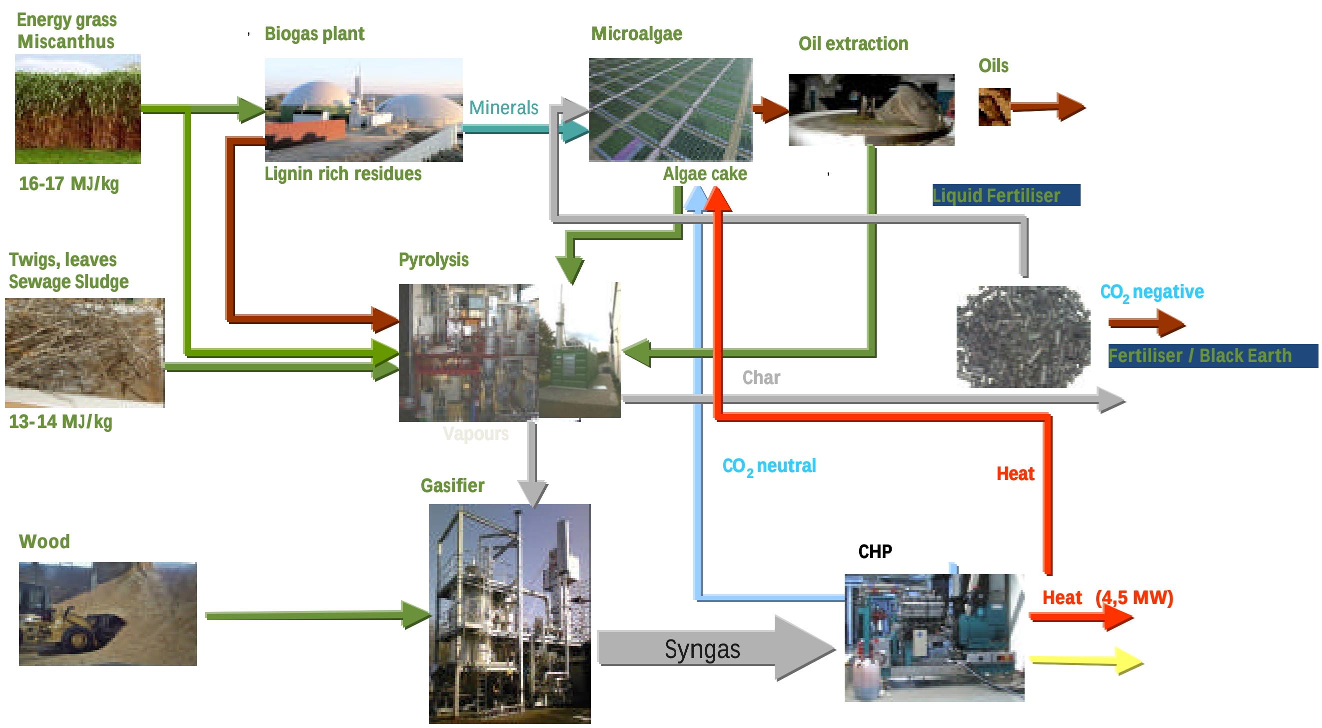

Fig. 1—BtVB process[4,13,14]

Fig. 2—Pyroformer

(WHC) and thus black earth can preserve water longer times than natural soil. Field studies[16] and Lab experiments (Supergen-Project Aston University)[17] have shown that black earth is promoting plant growth not only due to its content of fertilizer but also due to its general properties. WHC in the age of climate change is a more and more important property as longer and more intensive dry seasons may appear.

Pyroformer (Pyrolysis Reactor)

Principles of intermediate pyrolysis for biomass have been developed over the last few years by Hornung and co-workers at Aston University. The system produces good performance in conditioning biomass for heat and power and delivery of dry char residue for further purposes. Specifically for BtVB, a new pyrolysis reactor with improved design features (pyroformer: Fig. 2) has been developed to realize even more suitable pyrolysis chars for sequestration. Reactor in principle has a coaxial screw system where inner screw transports the feed from one end to the other end of reactor and outer screw transports a fraction of the char produced during pyrolysis. Transport of char not only ensures better heat transfer but also acts as a reforming agent with in the process[3]. Residence time for solid feed inside the reactor can be very carefully adjusted by changing the speed of screw.

Difference to Alternative Refinery Concepts

By coupling pyrolysis directly to fluidised bed gasifier, one can avoid the necessity of high sensible process components (condensation, filtration and aerosol precipitation) and a broad spectrum of bio resources can be used in the process without any risk[18-21]. Just for heating of the reformer part, gasifier fraction of the total char produced will be used. Remaining char is used for generation of black earth and for fertilizer recirculation. Feedstock may be rich or low in ash. This is the big difference to existing gasifiers, which are optimised but limited in their usage to feed of special kind. Integrated production of algae, which can take up aqueous phases of all process units after micro filtration and is thus taking up all minerals and fertilizer, takes advantage of process heat and results in a negative overall CO_2 balance.

Conclusions

BtVB process is a very efficient cycle for thermal conversion of biomass. It is an integrated carbon negative system and offers a closed loop in terms of fertiliser, CO_2 and heat producing energy as syngas for multipurpose applications without any effluents. A very efficient fertilizer cycle can be achieved by introducing algae cultivation into the process and using lignin rich residues from biogas processes. Fertilizer as well as heat and CO_2 required are delivered by different process stages (biogas, gasifier, engines) and therefore cut the costs of algae production dramatically. Other feedstocks (agricultural residues and residue wood) will stabilize feedstock support even in winter times, when algae cultivations slow down in growing. Algae produced during summer has a higher amount than required, and can be conditioned and stored.

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