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Biomass Pyrolysis and its Potential for China

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Abstract

China has abundant resources of biomass characterised by agricultural wastes and residues distributed all over the country. To apply this kind of biomass on a large-scale, one appropriate technical route is to convert it into a liquid and to transport the bio-oil to a central site where it can be used as a feedstock for energy or chemicals. For both, economic perspectives and local biomass availability, it must be envisaged that the appropriate scale for a pyrolysis plant is to process approx. 1 to 2 tones of biomass per hour with a yield of bio-oil between 60~70 wt.% for different agricultural wastes and residues. In this paper a draft has been prepared for a tech-economic evaluation, from which it can be concluded that biomass pyrolysis has a good potential in China.

Keywords: Biomass; Pyrolysis; Bio-oil

1 Introduction

Biomass is the general terminology to describe all organic materials stemming from green plants that store solar energy in chemical bonds through photosynthesis. When the bonds among adjacent carbon, hydrogen and oxygen molecules are broken through digestion, combustion, or decomposition, these substances will release their stored chemic energy. Biomass has always been a major source of energy for mankind and is presently estimated to contribute to the order of 10-14% of the world's energy supply (Peter McKendry, 2002).

China has abundant biomass resources with an estimated annual amount of more than one billion tce (ton coal equivalent, or 25 EJ; Li Junfeng, 1997). The principal biomass resources are: (1) wastes and residues from agriculture and forest industries, (2) animal manure from medium and large-scale livestock farms, and (3) municipal solid waste. Among them, the wastes and residues from agriculture and forest industries whose annual productions are listed in Table 1 (Li Jingjing et al, 2001) are the primary biomass energy resource. From Table 1 it can be seen that biomass resource in China is characterised by wastes and residues from agricultural activities.

13 Table 1 Annual production of main biomass from agricultural and forestry in China

Biomass type	Straw	Wood residues	Rice husk	Bagasse	Total
Production (Mt)	655.9	110.6	42.1	21.2	829.8
Caloric value (GJ/t)	14.5	15.5	13.3	19.4	-
Energy value (EJ)	9.5	1.7	0.6	0.4	12.2

Table 2 summarises the energy consumption in China in 2000 (Eric D. Larson et al; 2003), from which it can be concluded that:

- The energy consumption in China is heavily dominated by coal, providing more than 60% of all consumed energy. This coal-based energy structure leads to high emissions of CO_2 and other pollutants in China.
- Biomass energy is the third important energy source, after coal and oil. Nevertheless, it only accounts for 10.8% of all consumed energy and only about 20% of available biomass resources are exploited. Therefore, biomass energy can play far more important role in the future energy consumption in China.

Table 2 Energy consumption of China in 2000

Energy source	Quantity (EJ)	Percentage
Coal	32.0	61.9
Oil	8.9	17.2
Natural gas	1.4	2.7
Hydro electricity	2.5	4.8
Nuclear electricity	0.3	0.6
Biomass energy	5.6	10.8
Other renewable energy	1.0	2.0
	51.7	100.0

2 Overview of biomass conversion

If biomass could be made available for energy use in order to replace fossil fuels, it often needs to be upgraded to overcome its disadvantages such as dispersed availability and low bulk density.

Combustion, gasification and pyrolysis are the main three thermo-chemical processes to convert biomass into heat or energy products. Combustion of biomass in air is used over a wide range of outputs to convert the chemical energy stored in biomass into heat, mechanical power or electricity using various items of process equipment, such as stoves, furnaces, boilers, steam turbines, turbo-generators. The scale of combustion plants ranges from very small-scale domestic stoves up to large-scale industrial plants. Co-combustion of biomass in coal-fired power plants is an attractive option because of its high conversion efficiency.

Gasification is the conversion of biomass into a combustible gas mixture by partial oxidation with air at high temperature. It is carried out typically at temperatures in the range 800-900ºC, producing gaseous products with a lower calorific value (about 4-6 MJ/Nm^3). The gas can be directly burnt in gas ovens or (after being cleaned) used as a fuel for gas engines. One of the most promising concepts is biomass integrated gasification/combined cycle, where gas turbines convert the gaseous fuel into electricity with a high overall efficiency.

Flash pyrolysis (or simplified as 'pyrolysis') is the conversion of biomass to a liquid (termed bio-oil), solid and gaseous fractions by rapidly heating biomass to about 500~600ºC in the absence of oxygen. Among the products, bio-oil is predominant with a yield between 60~70 wt.% for different biomass resources. As pyrolysis is a simple one-stage atmospheric process, it can be applied to convert biomass into bio-oil, which then can be used as feedstock for other processes such as combustion or gasification.

The main hurdles for large-scale implementation of biomass are the nature of biomass (non-uniform, low-energy density, large ash content), together with the usual inconsistency between the local availability of biomass and the demand for biomass related products (heat, electricity and chemicals). Usually, import/transport of fossil fuels is cheaper. Pyrolysis may be a process to overcome these hurdles. Biomass is transformed into a versatile liquid, easy to handle and to transport. In the present paper, the authors emphasise the pyrolysis technology that has been demonstrated on various resources by BTG (Biomass Technology Group B.V., Enschede, Netherlands), which can be applied in China to convert various agricultural wastes and residues into bio-oil. Bio-oil is a mixture of oxygenated organic compounds (~75%) and water (~25%). Research has shown that bio-oil has the following advantages:

- Bio-oils from different biomass resources are easily mixed, which makes them suitable for application at large-scales where bio-oils from various resources can be used.
- Bio-oil has a viscosity of approx. 40cP, which makes it suitable to be pumped and atomised.
- Bio-oil has a volumetric energy density of about 20 GJ/m^3 which is much higher than that of agricultural wastes and residues (about 2 GJ/m^3). Therefore, bio-oil is convenient and cheap to be transported and stored.
- The ash content contained in bio-oil is a factor of 100 lower than in biomass. The alkalis always present in biomass remain in the char product, which makes bio-oil suitable for applications requiring a low ash content of the input material.

In summary, combustion and gasification are economically and efficiently feasible only on a large scale. But, enormous logistic problems can be foreseen with respect to collecting, transporting, storing and handling for agricultural wastes and residues. If pyrolysis is applied to locally convert biomass into oil that is transported from various places to a central site and is used as the feedstock for combustion or gasification, the hurdles can be overcome in an easy and cheap way.

3 Application analysis of biomass pyrolysis in China

3.1 Moderate capacity of pyrolysis equipment and its capital cost

In this study, the analysis of biomass resources for pyrolysis is focused on agricultural wastes and residues such as rice husk and various straws. Rice husk is of no use in the present situation (or is combusted at low efficiencies) and is already available at the generally small rice plants. Various straws are left on the fields and usually burned out. In the east and middle of China, the estimated average farmland is 50 ha/km^2 and the average annual production of biomass is 10 ton/ha. Some of the agricultural wastes and residues are used for other purposes such as fertiliser, animal forage, raw material for paper, etc. It is supposed that 30% of all agricultural wastes and residues can be used as the feedstock for pyrolysis. Based on these deductions, the available amount of biomass for pyrolysis annually produced in an area with different radius is shown in Figure 1.

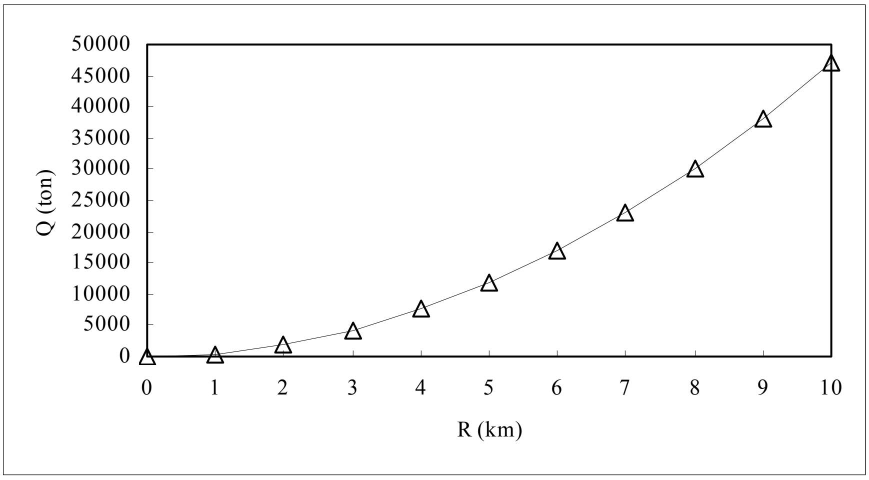

Figure 1 Available amount of biomass for pyrolysis versus collection radius

The primary principle to determine the moderate capacity of pyrolysis equipment is to decrease the production cost of bio-oil which mainly depend on the depreciation of the pyrolysis equipment and the transportation cost of biomass (see Table 4). In general, the higher the capacity of the pyrolysis equipment, the lower its capital cost of per unit and the lower its depreciation cost. But on the other hand, the area of biomass collection will be larger and the cost of biomass transportation will be higher. Considering the actual situation in Chinese rural areas, the feasible distance is 5 or 6 km for farmers to deliver biomass to pyrolysis plants at low price. Correspondingly, it is moderate for a set of pyrolysis equipment to process 1 to 2 ton biomass per hour, based on Fig. 1 (operation time: 24 hr per day and 300 days per year).

Table 3 gives the estimated capital cost of the pyrolysis equipment with a capacity of 2t biomass per hour. The total capital cost of 4,000,000¥ (note: 1¥ = 1Yuan RMB = 0.12US$) includes the capital cost of the additional equipment (dryers and shredders), but does not include the additional costs for licensing the technology.

Table 3 Capital costs of pyrolysis plants with a capacity of 2t biomass/hour

Cost factor	Capital cost (10^4¥)
Pyrolysis equipment	250
Equipment manufacture (material and labour)	150
Hand factor (control, software, etc.)	40
Infrastructure and installation	40
Others	20
Additional equipment	100
Shredder and dryer	40
Vessel for bio-oil storage	60
Unforeseen	20
Total	**370**

3.2 Production cost of bio-oil

Pyrolysis requires small (<10mm) and dry (<10wt% moisture) biomass feedstock, which demands most of agricultural wastes and residues have to be dried and shredded. The components of bio-oil production cost are all listed in Table 4 based on following supposition,

- The normal life-time of pyrolysis equipment is about 50,000 hours and its depreciation is 80 Yuan per hour.
- The caloric values of rice husk and wheat straw are 15MJ/kg and 17MJ/kg, and their bio-oil yields are 60% and 65%, respectively.
- Other suppositions are seen in Table 4.

Table 4 Production cost of bio-oil (¥/ton)

Cost factor	Rice husk	Wheat straw
Biomass price	150(¥/ton)×1.67(ton) = 251	170(¥/ton)×1.54(ton) =262
Pre-treatment	10(¥/ton)×1.67(ton) = 8.5	15(¥/ton)×1.54(ton) = 15.4
Depreciation	80(¥/h)×0.84(h) = 67.2	80(¥/h)×0.77(h) = 61.6
Maintenance	5% of depreciation = 3.4	5% of depreciation = 3.1
Labour cost	6×5(¥/h)×0.84(h) = 25.4	6×5(¥/h) ×0.77(h) = 22.7
Electric fee	0.50(¥/kWh)×40(kW)×0.84(h)=17	0.50(¥/kWh)×40(kW)×0.77(h)=15
Unforeseen	10% of total above = 37.3	10% of total above = 38.2
Total	410	420

3.3 Retail price of bio-oil

Bio-oil can be directly used as fuel in boilers to produce heat and steam. For this use, its retail price can be determined to be 850 ¥/ton based on following factors:

- The current market price of fuel oil in China is about 3000 ¥/ton. So, the equivalence price of bio-oil can be estimated to be 1140¥/ton as the caloric values of fuel oil and bio-oil are 42 MJ/kg and 16 MJ/kg, respectively.
- Considering that the users of bio-oil may need to modify their existing equipment, the selling price for bio-oil should be lower than the equivalence price. Therefore, a price of 1000¥/ton may be acceptable for them.
- Considering transportation costs and retailers profits, the retail price of bio-oil for pyrolysis plant can be determined to be 850 ¥/ton.

3.4 Anticipated profit for a pyrolysis plant

From the above analysis, it can be seen that the anticipated profit for a pyrolysis plant to produce and sell bio-oil is about 400 ¥/ton (see Table 5), which shows that biomass pyrolysis has a good potential in China.

Table 5 Anticipated profit for a pyrolysis plant (note: rice husk as feedstock)

Item	Anticipated profit
Annual production of bio-oil	1.2(t/h)×24(h/d)×300(d/y) = 8,640(t)
Annual total profit (no tax)	400 (¥/t)×8,640(t) = 3456000(¥) = 345.6(×10^4 ¥)
Pay-back time for investment	0.9 (year)

4 Conclusions

- China has an enormous amount of biomass resources. Biomass consumption amounts to 10.8% of the total energy consumption and about 20% of available biomass resources are exploited. Therefore, biomass energy can play far more important role in the future energy consumption in China.
- Chinese biomass is characterised by agricultural wastes and residues. To apply these biomass resources, an appropriate technical route is to use pyrolysis to locally convert them into bio-oil, and to transport the oil to a central site where it can be used as feedstock for the production of heat-energy or chemicals in slightly adapted existing equipments.
- As a compromise between biomass availability and investment costs, the moderate capacity of biomass pyrolysis equipment is to process 2 tons of biomass per hour. This concept promises large profit for operators of pyrolysis plants.
- Biomass pyrolysis has a good chance of application in China, if this technology is mature and the route of application is correctly chosen.

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