

# **MICROWAVE PLASMA BIOMASS GASIFYING FIXED BED GASIFIER AND PROCESS**

## **FIELD OF THE INVENTION**

[0001] The invention relates to the gasification of biomass and solid wastes, and more particularly to a gasifier and a method for gasifying biomass and solid wastes to synthesize high quality syngas in the presence of microwave plasma.

## **BACKGROUND OF THE INVENTION**

[0002] China is rich in biomass resources including cotton stalks, straw, twigs, and rice husk. As conventional primary energy sources such as fossil fuel are daily decreasing, people pay more and more attention to low calorific fuels.

[0003] Meanwhile, with the growing of environmental awareness, higher efficiency and lower contamination of high technology has gradually been adopted by industrial production.

[0004] Currently, the fixed bed gasification has defects such as low gasification temperature, high tar content, and low-quality syngas. Low gasification temperature results in high content of tar in the syngas. The tar is difficult to remove and easily blocks and corrodes the valves, pipes, and auxiliary equipment. The removal of the tar costs much. With the development of microwave technology, microwave plasma, with its own excellent characteristics, has widely applied to low temperature chemical vapor deposition gradually (CVD), rapid preparation of optical fibers, submicron etching of chips, surface modification of polymer materials, microelectronic materials processing, and so on.

[0005] The invention adopts microwave and plasma to gasify biomass fuel with high

efficiency, which provides a new way for the synthesis of syngas using biomass fuel and wastes.

## SUMMARY OF THE INVENTION

[0006] In view of the abovedescribed problems, it is one objective of the invention to provide a fixed bed gasifier and a method using the same for the gasification of biomass to synthesize high quality syngas, particularly to synthesize the syngas comprising CO and H<sub>2</sub> with characteristics of economy and high efficiency.

[0007] To achieve the above objective, the following technical schemes are adopted.

[0008] A microwave plasma based fixed bed gasifier of biomass, comprising a vertically disposed furnace body, a monitoring unit, and a microwave plasma generating device, the furnace body comprising a material and fuel inlet, a syngas outlet, an oxygen/vapor inlet, and a slag outlet, wherein the furnace body comprises a clearance zone in an upper part thereof and a fixed bed zone in a lower part thereof; the slag outlet is disposed at a bottom of the furnace body; the monitoring unit is disposed close to the syngas outlet; and at least one microwave plasma generating device is disposed on the furnace body.

[0009] Preferably, a first microwave plasma generating device is disposed between the fixed bed zone in the lower part of the furnace body and the material and fuel inlet, and a second microwave plasma generating device is disposed in the clearance zone in the upper part of the furnace body; the first microwave plasma generating device comprises two or three layers of microwave plasma generators, the second microwave plasma generating device comprises one or two layers of microwave plasma generators, and each layer of the microwave plasma generators comprises three or four evenly distributed working gas inlets.

[0010] Preferably, the first microwave plasma generator has large power and small

electrode gap, and produces high temperature of plasma; the second microwave plasma generator has large electrode gap, strong plasma activity, and wide volume range.

[0011] Preferably, a microwave power source of the microwave plasma generators has a basic frequency of 2.45 GHz, and a power of a single microwave plasma generator is within 200 kW.

[0012] Preferably, an upper oxygen/vapor nozzle is disposed in the clearance zone of the furnace body, and a lower oxygen/vapor nozzle is disposed in the fixed bed zone of the furnace body.

[0013] A method of gasification using the gasifier comprises:

[0014] 1) feeding biomass fuel and waste into the furnace body via a feeder, allowing the biomass fuel and waste to be combusted and gasified in the fixed bed zone to yield high temperature flue gas, allowing the flue gas to flow upward to exchange heat with newly-fed biomass fuel and waste in a feeding zone of the gasifier, and meanwhile allowing the flue gas to react with vapor sprayed from the lower oxygen/vapor nozzle and with a plasma oxidizer generated by the first microwave plasma generator to yield syngas, of which a chemical equation being:  $2C + O_2 = 2CO$ ,  $C + H_2O = CO + H_2$ , a gasification temperature being between 700 and 1600°C;

[0015] Within the temperature range, the microwave-excited plasma oxidizer has high degree of ionization, high degree of dispersion, and strong oxidation activity and chemical reactivity. Thus, even in a relatively low ambient temperature, the chemical reaction can proceed. The conversion efficiency of the biomass fuel is high, and the syngas comprising CO and  $H_2$  has high quality and little tars.

[0016] 2) allowing the syngas to flow upward to the clearance zone, where tars in the syngas are cracked and hydrocarbons in the syngas are converted in the presence of plasma generated by the second microwave plasma generator;

[0017] 3) allowing coke residues to fall downward to the fixed bed zone and release thermal energy to maintain the temperature of the fixed bed zone, and discharging slags from the slag outlet; and

[0018] 4) monitoring in real time a temperature and components of the syngas by the monitoring unit disposed close to the syngas outlet to maintain process parameters within a preset range.

[0019] In step 1), the gasification temperature is between 700 and 1600°C; and in step 4), the temperature of the syngas is within 1200°C.

[0020] In step 1), the gasification temperature is between 750 and 950°C.

[0021] In step 1), the vapor sprayed from the lower oxygen/vapor nozzle operates to increase the vapor concentration thereby prompting the reaction between the carbon residues and the vapor; in step 2), a total power of the second microwave plasma generator meets the requirement for supplying thermal energy for the reaction equilibrium; in step 2), the appropriate high temperature vapor is sprayed from the upper oxygen/vapor nozzle to prompt the cracking reaction of the tars.

[0022] Advantages according to embodiments of the invention are summarized as follows.

[0023] 1. In the presence of high degree of ionization and high degree of dispersion of microwave plasma, the biomass fuel in the gasifier is converted with high efficiency, and the cold gas efficiency is significantly improved compared to that in conventional gasification processes, exceeding 85%.

[0024] 2. The microwave plasma generator disposed in the clearance zone of the gasifier facilitates the unbalance cracking of tars in the syngas, and thus the syngas contains little or no tars, which can be directly used in industry, with simple process and good economic efficiency.

[0025] 3. The gasifier has no specific requirement on the particle size of biomass fuel, primary crushing can meet the requirement of particle size, and thus the production costs are low, with good economic efficiency.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. 1 shows a schematic diagram of a fixed bed gasifier of biomass and a flow chart of a gasification method using the same according to one embodiment of the invention.

[0027] FIG. 2 is a sectional view taken from Line A-A of FIG. 1.

[0028] In the drawings, the following reference numbers are used: 1. Feeder; 2. Furnace body; 3. Microwave plasma generator; 4. Lower oxygen/vapor nozzle; 5. Upper oxygen/vapor nozzle; 6. Monitoring unit; 7. Slag outlet; 8. Clearance zone of gasifier.

## DETAILED DESCRIPTION OF THE EMBODIMENTS

[0029] For further illustrating the invention, experiments detailing a gasifier and a method for gasifying biomass and solid wastes to synthesize high quality syngas are described below. It should be noted that the following examples are intended to describe and not to limit the invention.

[0030] A furnace body 2 is a vertically disposed cylinder, a clearance zone 8 is disposed at the uppermost of the furnace body, and a fixed bed zone receiving microwave plasma is disposed at the lowermost of the furnace body. A vertical downward slag outlet 7 is disposed at a bottom of the furnace body. An upper oxygen/vapor nozzle 5 is disposed in the clearance zone 8 of the furnace body, and a lower oxygen/vapor nozzle 4 is disposed in the fixed bed zone of the furnace body. Both the nozzles can be controlled by switches

to regulate the flow rate. The furnace body 2 is cylindrical, or a combination of a cone and a cylinder.

[0031] A feeder 1 is disposed in the middle of the furnace body 2 and communicates with the furnace body 2 via an inclined feeding chute. The feeding mode can optionally be screw feeding, without the need of the inclined feeding chute.

[0032] The number of the microwave plasma generator is determined by the content of moisture and volatile components in the biomass fuel. As the biomass fuel contains high content of moisture (about 20%) and low caloric value, in this example, the first microwave plasma generating device comprises two or three layers of microwave plasma generators 3 (in FIG. 1, there are two layers of microwave plasma generators), which are centrally disposed below the feeder 1 and slightly higher than the bed material position in the fixed bed, and each layer of the microwave plasma generators comprises three or four evenly distributed working gas inlets. The similar arrangement of the microwave plasma generators such as being disposed above the feeder is also acceptable. The second microwave plasma generating device is disposed in the clearance zone which is above the feeder 1, and comprises one or two layers of microwave plasma generators, each layer of the microwave plasma generators comprises three or four evenly distributed working gas inlets (in FIG. 2, there are three working gas inlets).

[0033] The first microwave plasma generator 3 has large power and small electrode gap, and produces high temperature of plasma; the second microwave plasma generator 3' has large electrode gap, strong plasma activity, and wide volume range, which is configured to crack the tars in the syngas, and to convert hydrocarbons such as methane in the syngas. Finally, the tar content in the syngas is reduced to meet the direct usage level in industry, and the hydrocarbon content is also reduced, which is conducive to the subsequent carbon removal.

[0034] The microwave power source of the microwave plasma generators has a basic

frequency of 2.45 GHz, and a power of a single microwave plasma generator is within 200 kW.

[0035] The total power of the second microwave plasma generator meets the requirement for supplying thermal energy for the reaction equilibrium.

[0036] A monitoring unit 6 is disposed close to the syngas outlet at the top of the furnace body 2 to monitor in real time the temperature and components of the syngas to maintain process parameters within a preset range.

[0037] The biomass fuel and waste are fed into the furnace body 2 via the feeder 1 and gasified quickly in the fixed bed zone of the gasifier. Firstly, the fuel particles are pyrolyzed under high temperature to yield a large amount of volatile components and semi-coke residues. The volatile components react with oxygen and vapor in the presence of high activity of plasma generated by the microwave plasma generator. To regulate the temperature of the fixed bed zone can ensure the smooth operation of the gasification process. If the furnace temperature is too low, the working gas such as oxygen should be complemented in large, and meanwhile the microwave power of the microwave plasma generator 3 and the flow rate of the working gas are adjusted accordingly, vice versa. The vapor sprayed from the lower oxygen/vapor nozzle 4 operates to increase the vapor concentration, thereby prompting the reaction between the carbon residues and the vapor, improving the yield of  $H_2$ , inhibiting the formation of the tars in the reaction zone, and enhancing the quality of the syngas.

[0038] With the feeding and gasification of the biomass fuel, the syngas flows upwards to the clearance zone and is cracked. The coke residues fall downwards to the fixed bed zone and release heat energy to maintain the temperature therein. The resulting slag is discharged from the slag outlet 7. In the clearance zone 8, the syngas is further cracked in the presence of high degree of ionization and high activity of plasma generated by the second microwave plasma generator. Appropriate high temperature vapour is sprayed

from the upper oxygen/vapor nozzle 5 for further cracking the tars in the syngas. Thus, the tar content is greatly reduced, which is conducive to the subsequent application.

[0039] The gasification temperature is between 700 and 1600°C; and the temperature of the syngas is within 1200°C. The gasification temperature is between 750 and 950°C.

[0040] To achieve the optimal working conditions and satisfy the overall performance requirement of the gasification, the key is to control the temperature of the entrained flow bed, and to regulate the oxygen flow rate, vapor flow rate, and microwave power. The monitoring unit disposed close to the syngas outlet can monitor the above parameters in real time, thereby controlling the gasification process by chain and by full automation and maintaining the operation stability of the gasifier.

[0041] While particular embodiments of the invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention in its broader aspects, and therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

## CLAIMS

1. Amicrowave plasma based fixed bed gasifier of biomass, comprising a vertically disposed furnace body, a monitoring unit, and a microwave plasma generating device, the furnace body comprising a material and fuel inlet, a syngas outlet, an oxygen/vapor inlet, and a slag outlet, wherein the furnace body comprises a clearance zone in an upper part thereof and a fixed bed zone in a lower part thereof; the slag outlet is disposed at a bottom of the furnace body; the monitoring unit is disposed close to the syngas outlet; and at least one microwave plasma generating device is disposed on the furnace body.
2. The gasifier of claim 1, **characterized in that** a first microwave plasma generating device is disposed between the fixed bed zone in the lower part of the furnace body and the material and fuel inlet, and a second microwave plasma generating device is disposed in the clearance zone in the upper part of the furnace body; the first microwave plasma generating device comprises two or three layers of microwave plasma generators, the second microwave plasma generating device comprises one or two layers of microwave plasma generators, and each layer of the microwave plasma generators comprises three or four evenly distributed working gas inlets.
3. The gasifier of claim 2, **characterized in that** the first microwave plasma generator has larger power and smaller electrode gap, and produces higher temperature of plasma than that of the second microwave plasma generator; whereby the second microwave plasma generator has larger electrode gap, stronger plasma activity, and wider volume range than that of the first microware plasma generator, wherein a microwave power source of the first and second microwave plasma generators has a

basic frequency of 2.45 GHz, and a power of a single microwave plasma generator is within 200kW.

4. The gasifier of any one of claims 1-3, **characterized in that** an upper oxygen/vapor nozzle is disposed in the clearance zone of the furnace body, and a lower oxygen/vapor nozzle is disposed in the fixed bed zone of the furnace body.
5. A method of gasification using the gasifier of any one of preceding claims, the method comprising:
  - 1) feeding biomass fuel and waste into the furnace body via a feeder, allowing the biomass fuel and waste to be combusted and gasified in the fixed bed zone to yield high temperature flue gas, allowing the flue gas to flow upward to exchange heat with newly-fed biomass fuel and waste in a feeding zone of the gasifier, and meanwhile allowing the flue gas to react with vapor sprayed from the lower oxygen/vapor nozzle and with a plasma oxidizer generated by the first microwave plasma generator to yield syngas, of which a chemical equation being:
$$2C + O_2 = 2CO, C + H_2O = CO + H_2,$$
a gasification temperature being between 700 and 1600°C;
  - 2) allowing the syngas to flow upward to the clearance zone, where tars in the syngas are cracked and hydrocarbons in the syngas are converted in the presence of plasma generated by the second microwave plasma generator;
  - 3) allowing coke residues to fall downward to the fixed bed zone and release thermal energy to maintain the temperature of the fixed bed zone, and discharging slags from the slag outlet; and
  - 4) monitoring in real time a temperature and components of the syngas by the monitoring unit disposed close to the syngas outlet to maintain process parameters within a preset range.

6. The method of claim 5, **characterized in that** in step 1), the gasification temperature is between 700 and 1600°C; and in step 4), the temperature of the syngas is within 1200°C.
7. The method of claim 6, **characterized in that** in step 1), the gasification temperature is between 750 and 950°C.
8. The method of claim 6 or 7, **characterized in that** in step 1), the vapor sprayed from the lower oxygen/vapor nozzle operates to increase the vapor concentration thereby prompting the reaction between the carbon residues and the vapor; in step 2), a total power of the second microwave plasma generator meets the requirement for supplying thermal energy for the reaction equilibrium; the appropriate high temperature vapor is sprayed from the upper oxygen/vapor nozzle to prompt the cracking reaction of the tars.