December 2006 Volume 1 Issue 2-4

CHEMICAL TECHNOLOGY

An Indian Journal

Trade Science Inc.

Full Paper

CTAIJ, 1(2-4), 2006 [101-107]

Experimental Investigation On The Conversion Of Agricultural Waste To Bio-Gas

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Received: 27th November, 2006
Accepted: 12th December, 2006

Web Publication Date : 27th December, 2006

ABSTRACT

Agricultural waste such as rice husk and sawdust can be gasified to produce bio-gas which can be used as fuel or used to synthesize liquid fuel. In this work, gasification efficieny of agricultural waste with different equivalent ratio (ER) is experimentally investigated in a self-heated fluidized gasifier. The higher heat value (HHV) of bio-gas is more than 3.90MJ/Nm^3, and the energy conversion is more than 40% with an optimum ER. Energy conversion increased with the decreasing of ER. The energy input and output in the gasification system are calculated considering their commercial usage. The power input was 9.5kW, whereas the theoretic power output was more than 30kW. The tar waste water was treated by extraction.

KEYWORDS

Agricultural waste;
Gasification;
Energy balance;
ER;
Fluidized bed.

INTRODUCTION

Agricultural waste such as rce husk, straw and corn stalk is a mixture of hemicellulose, cellulose, lignin and other organic compounds. There are about 2.34×10^9 tons of straw all over the world in 1997 and crop production will continue to increase to feed the ever-increasing population[9]. 1.0×10^9 tons cereal straw was produced in one year in China alone[3]. For its low HHV, the agricultural waste can not be used as fuels by farmers. The environment was badly polluted by the waste combustion in outside, which was widely-used for agricultural waste treatment in contryside[2]. This means that envirment was polluted by CO and ash, and biomass energy was wasted. Some researchers[1,7] focused on the biodegradation of agricultural waste. Althrough biological methods are high seletive, they are just used in small scale[16] . Some other researchers[10, 11] use agricultural waste as animal feed. However, the commercial value of this technology and tar removal is not investigated.

Pyrolysis and gasification are more effective mehods of converting solid waste to energy[6, 13]. There are two favorable factors made this technology compellent. One is that pyrolysis and gasification systems can be designed and produced on a large scale[8, 12], the other is that the efficiencies of conversion are very high[14, 15] However, the energy input and output of in biomass gasification system is not caluculated, and the commercial and environmental benefits for using biomass are not evaluated by researchers. The tar wastewater produced in gasifcation process are not treated. The objective of this work is to study the gasification efficiencies of rice husk and sawdust in a fluidized bed gasifier, calculate the convertion efficiency, energy input and output based on pilot scale experiments and evaluate the commercial and environmental benefits of this system. The gasification parameters of two typical agricultural waste, sawdust and ricehusk, are also compared. Meanwhile, an extraction method is proposed to treat the tar wastewater.

EXPERIMENTAL

Materials and methods

The agricultural waste used is rice-husk from a mill factory and sawdust from a wood working company. The average size of a rice husk is 8 mm long, 2 mm wide and 1 mm thick, and the average equivalent diameter of sawdust is 0.34 mm. The density of rice husk and sawdust are 230 kg/m^3 and 480 kg/m^3, respectively. The HHV of rice husk and sawdust is about 14.1MJ/kg. TABLE 1 shows the proximate and ultimate analysis of the agricultural waste materials.

The bio-gas obtained from gasification is analyzed by an integrated online analyzer which combined with 3 infrared detectors (for CO_2, CO and CH_4) and 2 special detectors (for O_2 and H_2). The main parameters are shown in TABLE 2.

TABLE 1: Proximate (%) and ultimate analyses (% dry basis) of the agricultural waste

	Rice husk	sawdust
Proximate analysis		
Volatiles	87.0	88.2
Moisture	11.5	11.4
Ash	1.5	1.3
Ultimate analysis		
C	41.01	45.06
H	5.33	6.21
O	39.63	35.19

TABLE 2: Some parameters of online gas analyzer

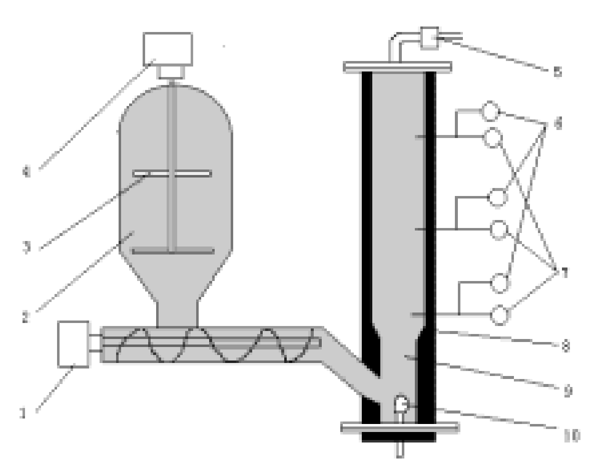
Type	Detected components	Scale	Output current
GXH-1050 infrared	CH_4	0-10%	4-20mA
GXH-1050 infrared	CO_2	0-20%	4-20mA
GXH-1050 infrared	CO	0-20%	4-20mA
JRD-1010	H_2	0-20%	4-20mA
JRC-1020	O_2	0-5%	4-20mA

The gasification experiments are carried out in a fluidized gasifier at 973K to 1123K. The feeder and gasifier are shown in figure 1. The entire system consists of the fluidized bed reactor, rotameters, manometers, thermocouple thermometers, screw feeder, air compressors, cyclone separators and purification system. The fluidized bed reactor consists of two parts. The lower part is a 100 mm ID and 1300 mm long tube and the upper part is a 165 mm ID and 2000 mm long tube. Both of them are made of high quality heat-resistant stainless steel tube and cement. The feeding rate was 20 kg waste/hr. The ER ranges from 0.14 to 0.26.

RESULTS AND DISCUSSION

Gasification experiment of rice husk and sawdust

The ER can be defined as the ratio of actual



1.screw feeder. 2.biomass storage. 3.stir. 4.timing electromotor. 5.pressure adjustor. 6.thermocoupler thermometer. 7.manometer. 8.pressure-resistant wall. 9.fluidized bed-reactor. 10.lighter

Figure 1: Screw feeder and fluidized bed system

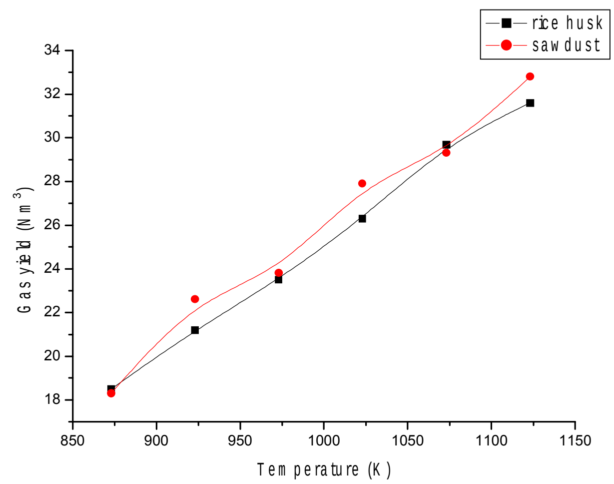


Figure 2: The gas yield of different gasification temperature (ER=0.14)

oxygen demand during gasification to the stoichiometric oxygen demand of biomass oxidation reaction. HHV, C conversion and energy conversion can be calculated by Equitions 1 to 3, respectively. The average composition of bio-gas with different ER and conversion ratio are shown in TABLE 3.

$$HHV(MJ/Nm3) = 41321CH4\% + 12636CO\% + 12759H2\% \quad (1)$$

$$Cconversion(\%) = \frac{\sum C(bio-gas)}{C(waste)} \quad (2)$$

$$Energyconversion(\%) = \frac{\sum HHV(bio-gas)}{HHV(waste)} \quad (3)$$

The experimental results show that sawdust has better gasification efficiency than rice husk. Both of the size of agricultural waste particles and their chemical composition have an influence on the gasification efficiency. Gasification of small particles (sawdust) is controled by kinetic process, whereas gasification of big particles (rice husk) is controled by a diffused process.

ER is an important factor to influence the gasification efficiency and the composition of bio-gas. The concentration of CO, H_2 and CH_4 increased regularly with the increase of ER (TABLE 3). Gasification with a small ER value has a good energy conversion and a high HHV. Furthermore, the total energy input is less than that of the large one, for the power cost of compressor is almost in a direct ratio with ER. The gas yield was mainly inflenced by temperature and ER. However, the influence of ER to gas yield is much less than that of temperature. The gas yield at same ER increases with the raising of the gasification temperature (Figure 2).

The gas yield of 1 kg biomass increases from 0.9 Nm^3 to 1.6 Nm^3 with the increase of temperature

TABLE 3: Composition of bio- gas and conversion ratio (%)

	Rice husk				sawdust			
ER	0.14	0.18	0.22	0.26	0.14	0.18	0.22	0.26
Gas yield (Nm^3/hr)	29.2	33.6	38.7	41.9.	29.5	34.1	38.5	42.4
CO	18.34	16.06	14.47	8.15	18.86	16.74	15.43	12.15
H_2	2.75	2.45	1.98	1.06	2.82	2.37	2.15	1.85
CH_4	2.99	2.19	1.67	1.04	3.54	2.85	2.34	2.21
HHV(MJ/Nm^3)	3.90	3.25	2.77	1.59	4.21	3.60	3.19	2.68
C conversion (%)	73.2	82.5	91.3	93.5	76.5	85.4	92.4	95.1
Energy conversion (%)	40.4	38.7	38.1	23.6	44.0	43.5	43.6	40.3

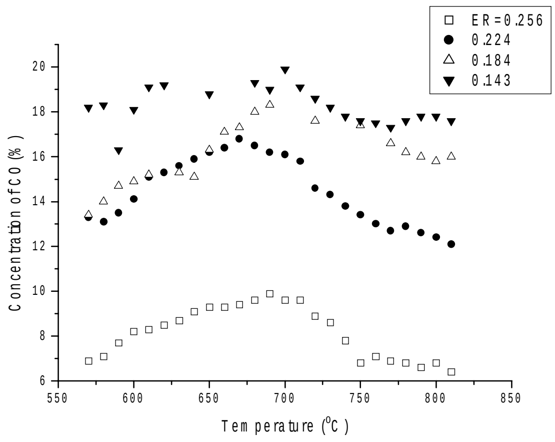


Figure 3: The concentration of CO in producer gas under different gasification temperatures and ER with the rice husk.

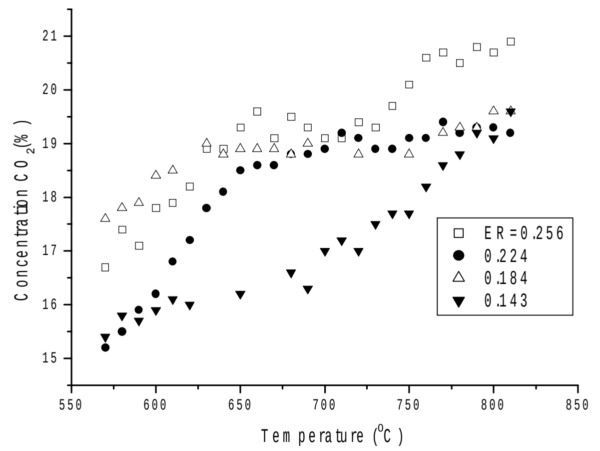


Figure 4: The concentration of CO_2 in producer gas under different gasification temperatures and ER with the rice husk

from 550°C to 850°C. At higher temperature, the char is easily reacted with CO_2 and steam to producer CO and H_2. Furthermore, the small molecular compounds are decomposed to gaseous compounds.

$$C + CO_2 = 2CO$$

$$C + H_2O = CO + H_2$$

$$C_xH_yO_z \rightarrow CO_2 + CO + C_nH_m + H_2$$

CO is the one of main components in gaseous products of gasification. The concentration of CO increases with the decrease of ER. However, the change of concentration is relatively small when ER<0.224. The maximum CO concentration of gaseous products can be obtained at 700°C (Figure 3).

The concentration of CO_2 in gaseous products incresed with the increase of temoerature while holding the ER constant. There are some increases of CO_2 concentration with the increase of ER, but a small change trend is observed from figure 4. As a self-heated fluidized bed system, the high temperature more than 1000°C is difficult to be obtained. The deoxidized reaction of CO_2 is uncompleted below 850°C. So the concenration of CO_2 in this work is high (Figure 4).

The concentration of H_2 is changed irregularly with the increase of temperature. However, the small ER is beneficial to the production of H_2. The concentration of H_2 is about 3% without steam addition (Figure 5).

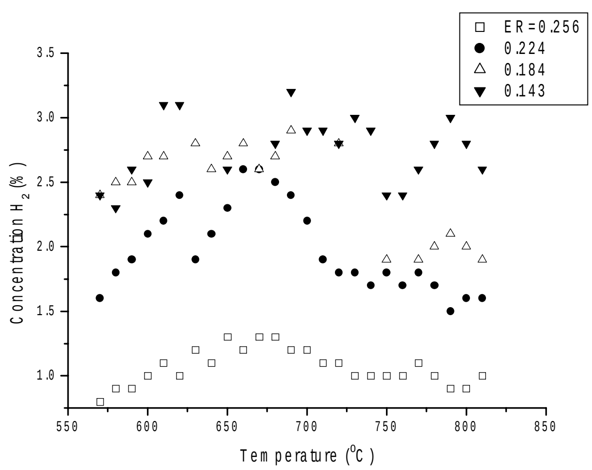


Figure 5: The concentration of H_2 in producer gas under different gasification temperatures and ER with the rice husk

The concentration of CH_4 in producer gas increases with the decrease of ER. It is influenced slightly by the change of temperature (Figure 6).

Figures 7 to 10 show the changes of gas composition with ER and temperature in sawdust gasification. Almost similar change trends of CO and CO_2 concentration as rice husk gasification are observed in sawdust gasification. However, the compositions of gaseous products are somewhat different. The concentration of CO in sawdust gaseous products is about 2 percent more than that in rice husk products while holding ER constant. The concentration of CO_2 in sawdust gaseous products is same as that in

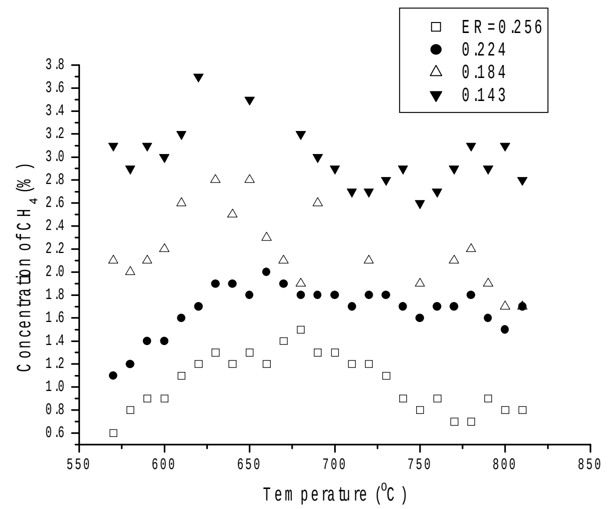


Figure 6: The concentration of CH_4 in producer gas under different gasification temperatures and ER with the rice husk

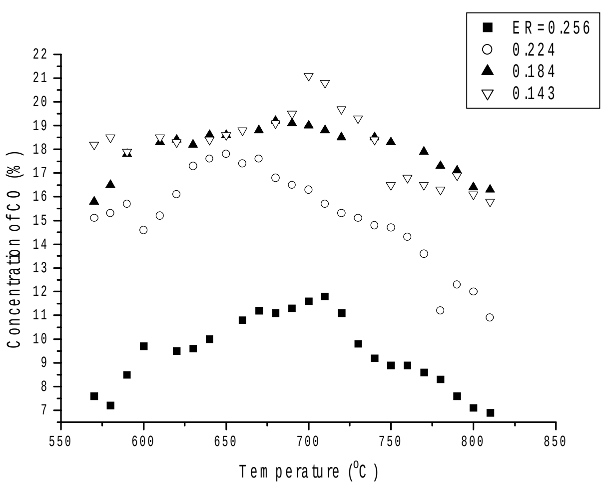


Figure 7: The concentration of CO in producer gas under different gasification temperatures and ER with sawdust

rice husk gaseous products.

The concentration of H_2 increases with the decrease of ER, and with the increase of temperature. The composition of H_2 is about 7% when ER equals to 0.14 and temperature is 820°C. Regular changes are observed in figure 9, for sawdust particles are small and easily fluidized.

The concentration of CH_4 decreases from 4% to 0 with the increase of temperature and ER. The opitimum condition for CH_4 production is ER=0.184 and at about 700°C.

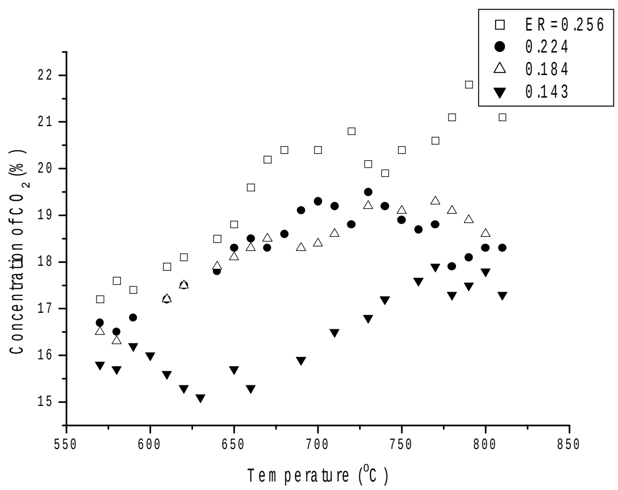


Figure 8: The concentration of CO_2 in producer gas under different gasification temperatures and ER with sawdust

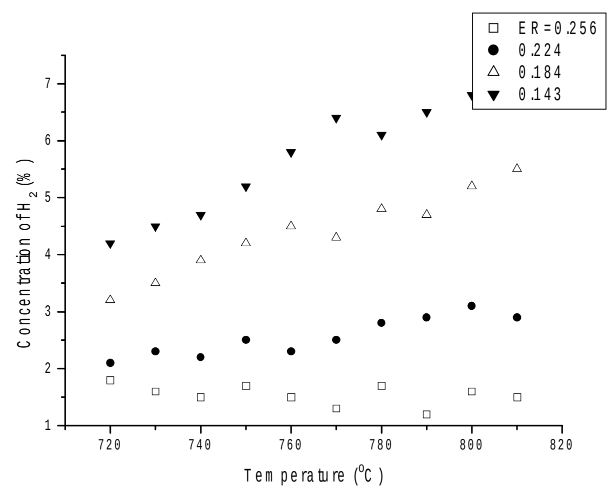


Figure 9: The concentration of H_2 in producer gas under different gasification temperatures and ER with sawdust

Tar treatment

The bio-gas containing tar has to be purified before it is used as gas fuel. Washing with water is widely used for the removal of tar pollution. However, the tar wastewater is harmful to the environment and difficult to treat. An efficient system is used in our work to resolve the problem (Figure 11). The bio-gas is first washed by recycling water. A filter is used to remove the fine ash particles and some low boiling point organic compounds. When the COD of washed water was in excess of about 10000

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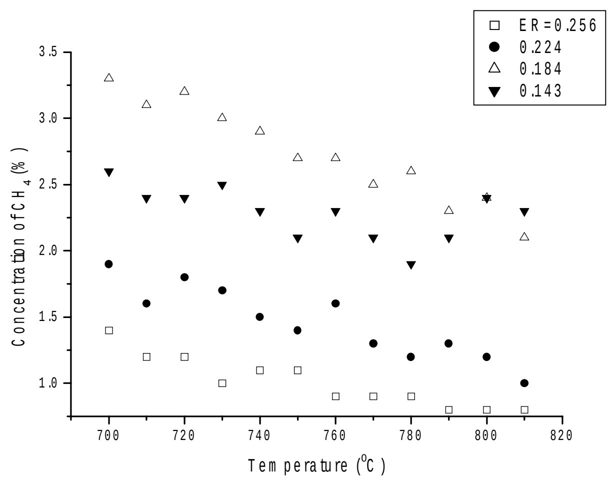
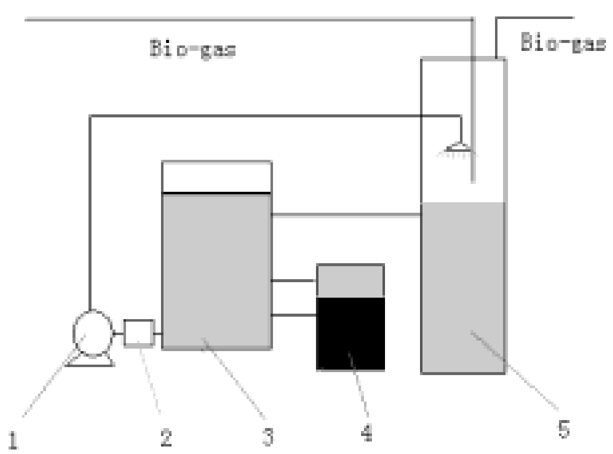


Figure 10: The concentration of CH_4 in producer gas under different gasification temperatures and ER with sawdust



1. Pump 2. Filter 3. Water tank 4. Extractor 5. Washing equipment

Figure 11: Gas washing and tar removal system

TABLE 4: Efficiency of extraction

	Original waste water	Extracted water	Efficiency
COD(mg/L)	15400	4220	82.6
Phenol(mg/L)	4250	260	93.9

mg/L, the water is extracted by N503 (commercial extractant, produced by Shanghai Institue of Organic Chemistry, China). Treated water was then recycled to the system. TABLE 4 shows that about 94% phenol and 83% COD are extracted. Phenol removal by extraction is researched in detail by[4].

Calculation of energy balance

The massive utilization of agricultural waste by gasification is determined by the commercial feasibility of this technology. This means that the output energy must more than input energy in gasification system. The input and output energy are compared under the conditions of maximum average energy conversion.

Input: Compressor 7.5kW
Screw feeder 1.5kW
Other 0.5kW
Total 9.5kW

Ouput: Rice husk
Total HHV of bio-gas=3.90MJ/Nm^3×29.2Nm^3/hr=113.9MJ/hr=31.6kW
Sawdust
Total HHV of bio-gas=4.21MJ/Nm^3×29.5Nm^3/hr=124.2MJ/hr=34.5kW

When temperature of bio-gas are about 623K, the heat energy can be partly used. The system can be run with net energy output according to above calculation.

Experiments were repeatable below a temperature of 1123K and a pressure of 0.8MPa. By using the online gas analyzer, only a 1% error margin existed in the results of gas composition. About 5% of errors existed in the feeding system of the biomass, and about 3% of errors existed in the air supply.

CONCLUSION

The agricultural waste such as rice husk and sawdust can be gasified to produce bio-gas which can be used as fuel or used to synthesize liquid fuel. In this work, gasification efficieny with different ER is investigated in a self-heated fluidized gasifier. Several conclusions wer obtained.

(1) Energy conversion increases with the decreasing of ER.
(2) The gasification of agricultutural waste has a commercial usage when the bio-gas is used efficiently (more than 30%).
(3) Gas yield increases with the increase of gasification temperature.
(4) The gasification efficiency of different agricultural waste varies.

ACKNOWLEDGEMENT

This research was supported by the CAS, MOST, NSFC and the University of Science and Technology of China.

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