November 7, SJTU, China

Research and Development of Biomass Conversion Technologies in Shanghai JiaoTong University, China

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There are 8 main parts

1.Introduction to Shanghai JiaoTong University(SJTU)

2.Biomass characteristics

3.Biomass fast pyrolysis for bio-oil production

4. Biochar Application for Soil Amendment

5.Gasification

6.Bioethanol

7.Biogas technology

8.Conclusion

1.Shanghai JiaoTong University(SJTU)

- Established in 1896
- There are 20 schools, including school of Agriculture and Biology, School of Mechanical and Power Engineering, School of Environment Engineering, etc.
- Students:44020; Teachers:2851
- Area of campus: about 333 ha.

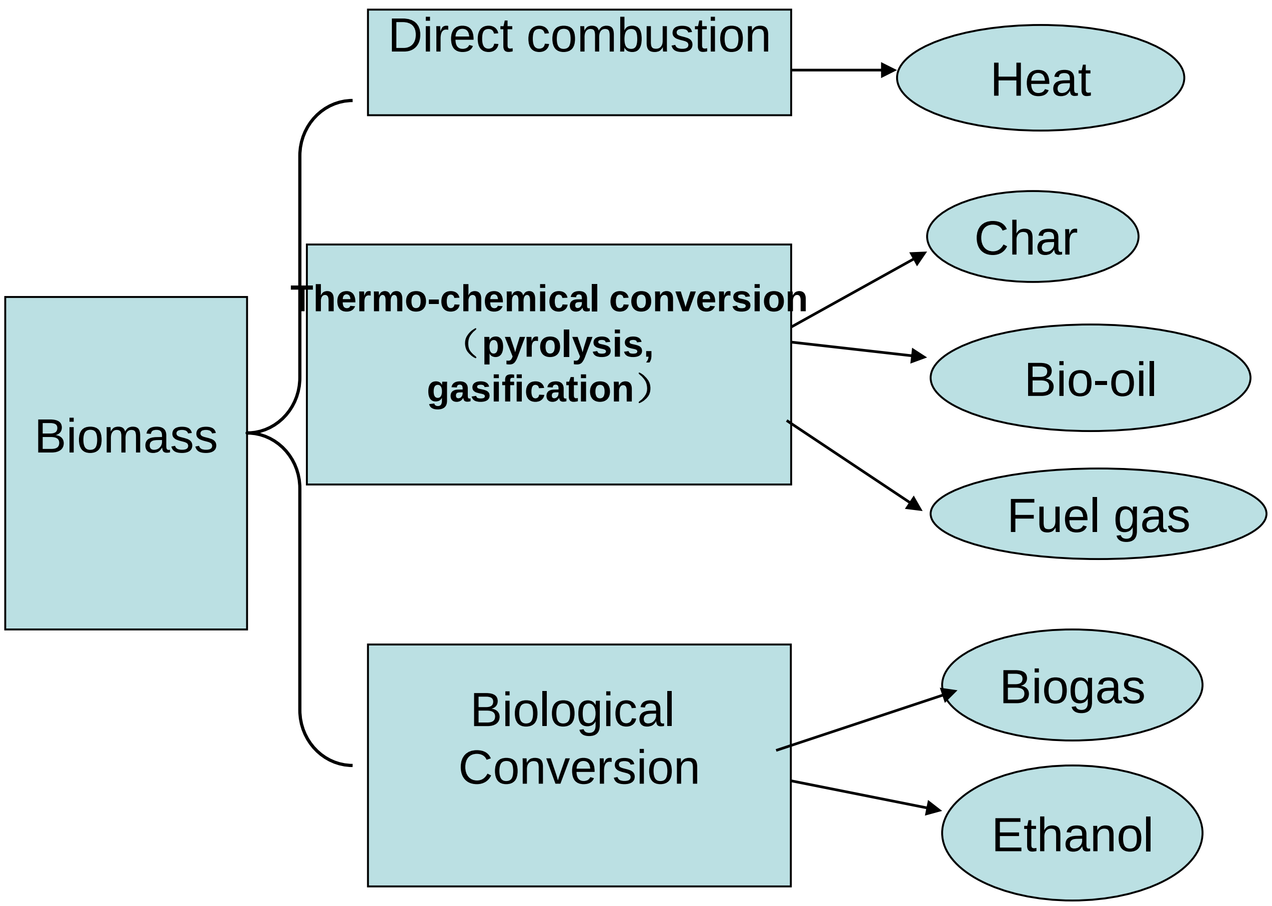
School of Agriculture and Biology (SJTU)

Biomass Energy Engineering Research Centre,

School of Agriculture and Biology , Shanghai JiaoTong University has a lot of experiences in the field of biomass energy and environment.

Including characterization of biomass, biomass pyrolysis, biochar, gasification, bioethanol, biogas, etc.

Biomass energy conversion technologies



2.Research on biomass characteristics

Objective: To establish database of biomass characteristics and provide a theoretical basis for utilization of biomass.

Sample source:

1) Various areas: Shanghai, Anhui and Jiangxi;

2) Various agricultural residue: Rice straw, wheat straw, corn stalk, rape straw and cotton stalk.

Samples: 275 samples;

3) Various manure: Pig, broiler, layer, dairy cow and beef.

Samples: 275 samples.

Characteristics of agricultural biomass: elemental analysis

Elemental analysis of livestock and poultry manure/%

	Manure of layer	Manure of pig	Manure of dairy cow
C	37.863±1.501	38.695±2.801	40.485±0.904
H	5.107±0.501	6.068±0.437	5.982±0.238
N	2.705±0.762	2.508±0.355	2.120±0.068
S	0.514±0.051	0.755±0.038	0.532±0.075
O	53.812±1.273	51.975±3.551	50.880±1.172

Elemental analysis of stalk and straw/%

	Rice straw	Corn stalk	Rape straw	Cotton stalk
C	40.745±1.426	41.811±2.843	38.618±1.433	43.993±1.488
H	5.644±0.326	5.868±0.517	5.737±0.383	5.877±0.372
N	0.906±0.362	1.35±0.358	0.456±0.215	1.233±0.46
S	0.815±1.581	0.367±0.045	0.932±0.225	0.417±0.16
O	46.81±5.434	47.587±2.409	54.257±1.598	48.317±1.209

Basic properties of agricultural biomass: proximate analysis

Proximate analysis of livestock and poultry manure /%

	Manure of layer	Manure of pig	Manure of dairy cow
Moisture	60.83±2.58	74.11±3.71	81.31±1.88
Crude ash	21.35±3.34	21.07±5.13	13.40±2.09
Volatile	54.89±6.11	56.49±3.63	59.75±2.20
Fixed carbon	15.73±1.19	13.51±1.05	17.97±4.25

Proximate analysis of stalk and straw /%

	Rice straw	Corn stalk	Rape straw	Cotton stalk
Moisture	4.21±0.67	5.46±3.30	4.23±1.52	3.13±1.44
Crude ash	14.00±1.23	5.84±1.75	7.66±0.83	6.63±0.15
Volatile	67.49±2.04	71.79±5.93	74.63±0.86	71.89±1.24
Fixed carbon	14.29±0.29	16.92±1.59	13.48±2.27	18.35±0.74

3.Biomas fast pyrolysis for bio-oil production
Mechanism of biomass pyrolysis

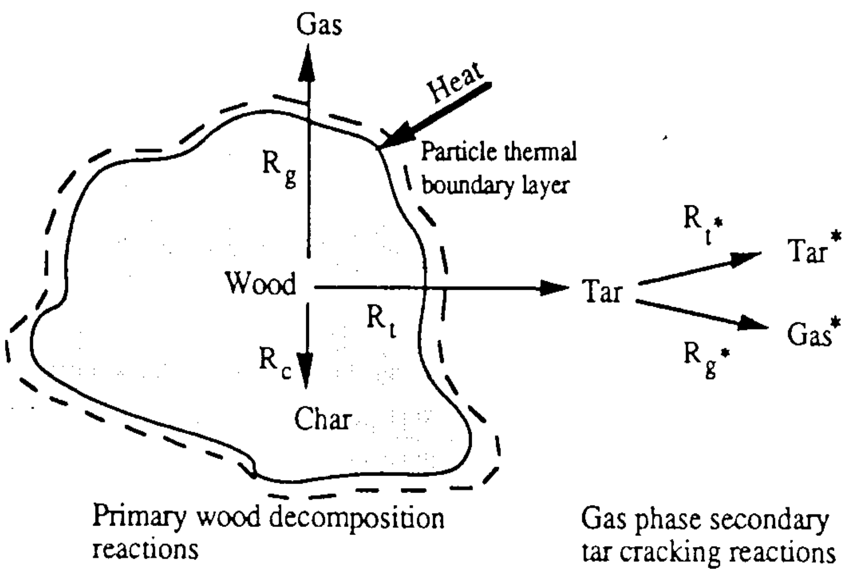


Fig.1 Sketch of a Decomposing Wood Particle Including the Reaction Paths Involved

If the pyrolysis conditions are proper, 100kg biomass can produce 60 kg bio-oil.

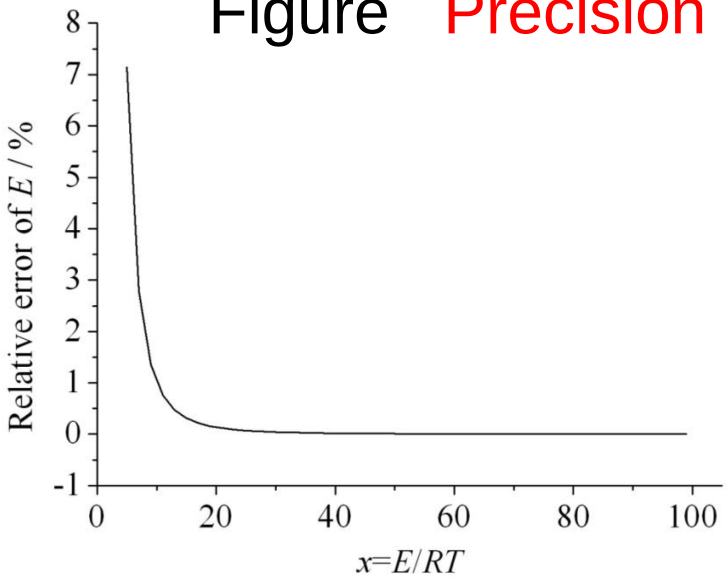
Pyrolysis kinetics -Systematic analysis of integral methods

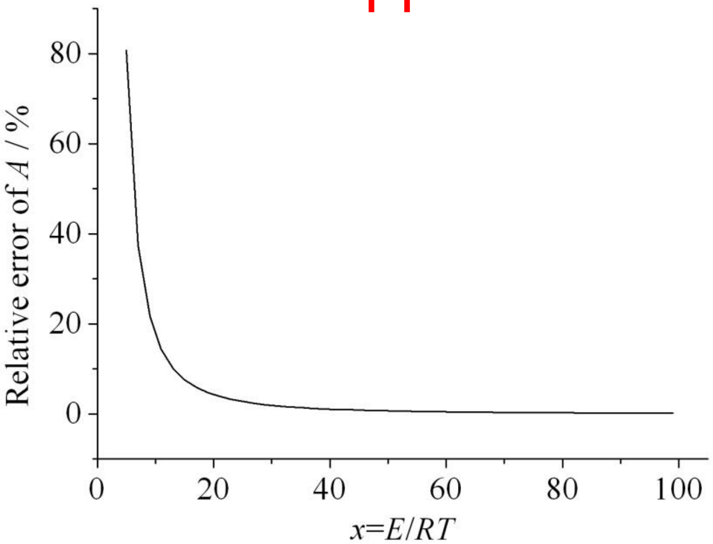
- Relative error of activation energy obtained by integral methods

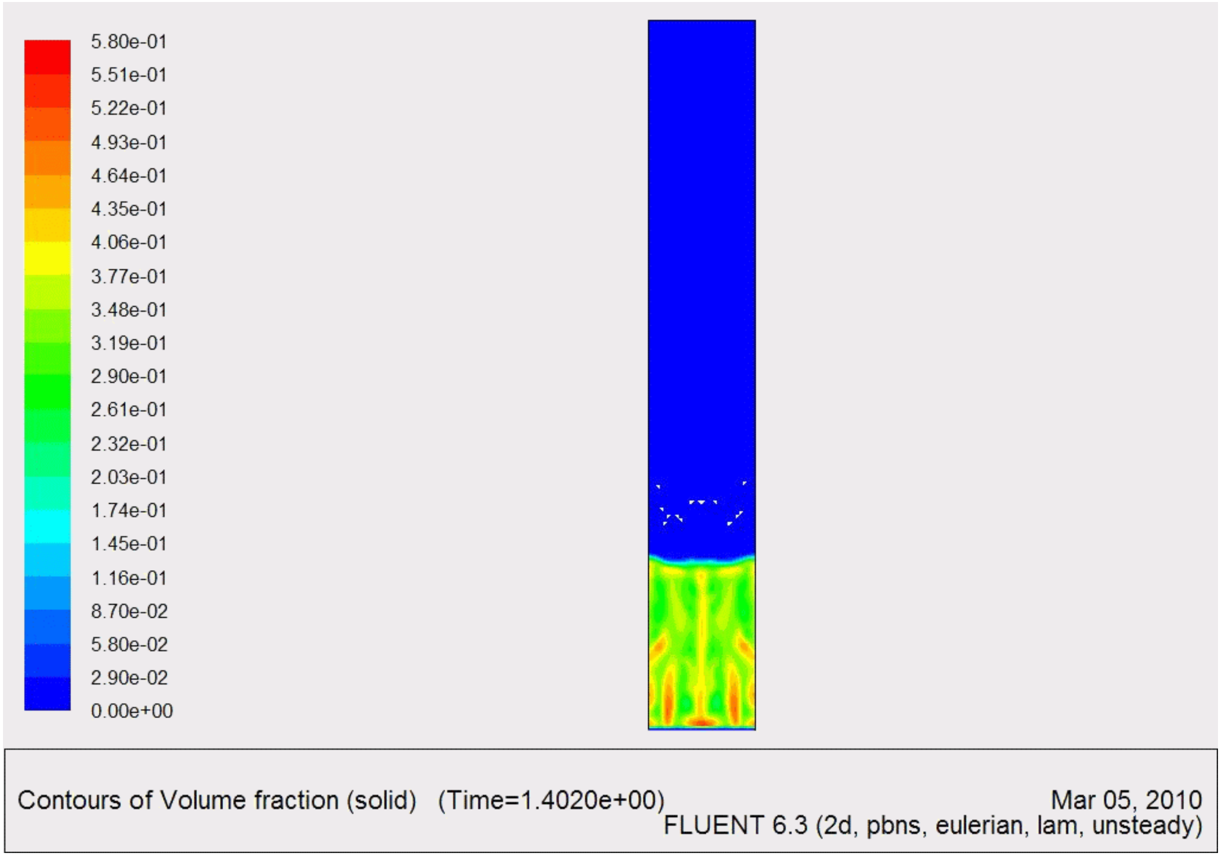
$$(\varepsilon_E+1)\left(1-\frac{d\ln h_1\left[(\varepsilon_E+1)u\right]}{d\left[(\varepsilon_E+1)u\right]}\right)=1-\frac{d\ln h(u)}{du}$$

- Relative error of frequency factor obtained by integral methods $\varepsilon_A=(\varepsilon_E+1)e^{\varepsilon_E u}\frac{h(u)}{h_1[(\varepsilon_E+1)u]}-1$

Figure Precision of Coats and Redfern approach







Result: when time is 4 s, the fluidization of sand is best

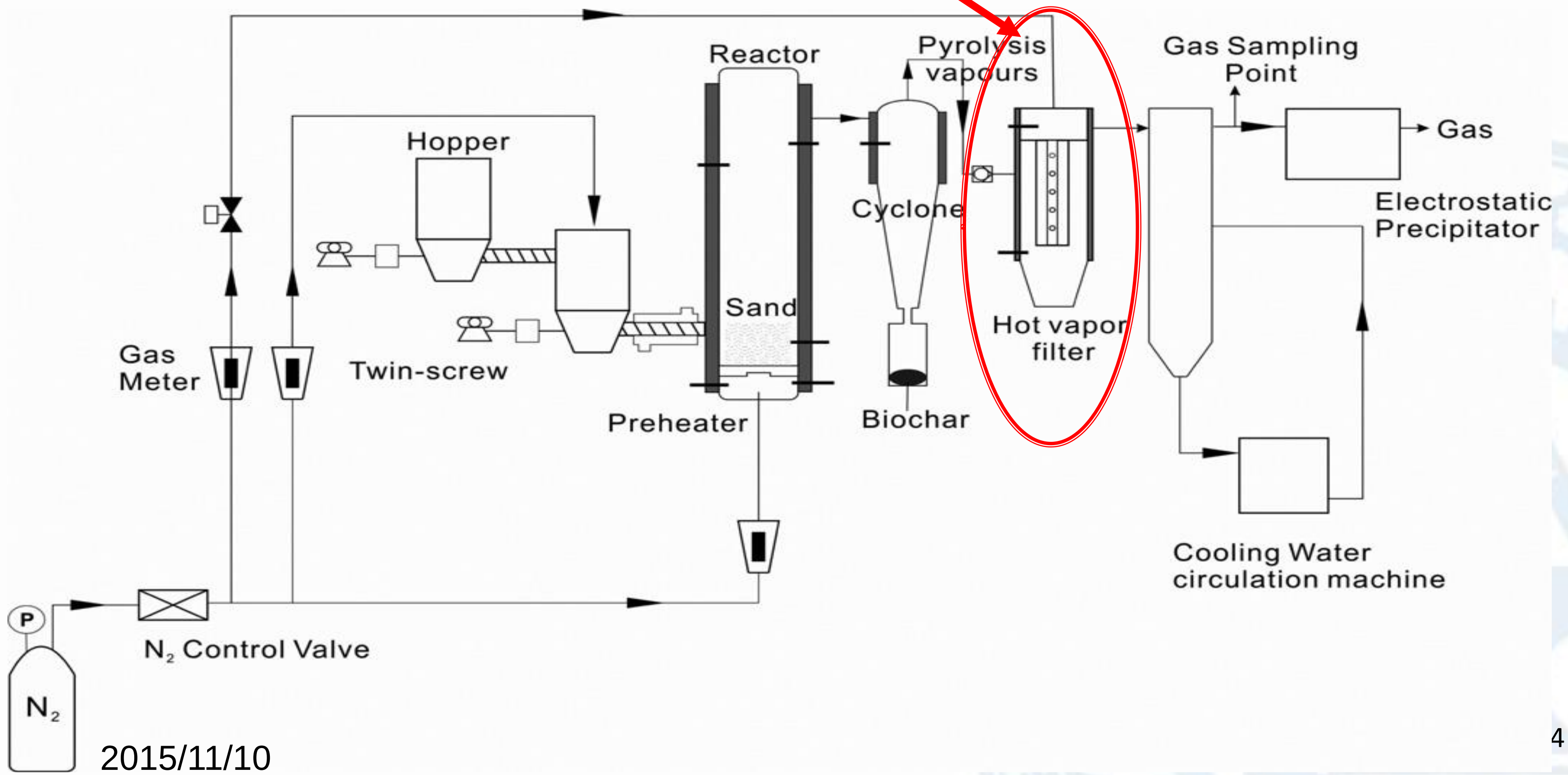
Simulation of sand in fluidized bed reactor

Fluidized bed reactor for biomass fast pyrolysis for bio-oil production developed by Shanghai JiaoTong University

- Biomass throughput:1-5 kg/h;
- Reactor Temperature:400-600° C
- Biomass particle size:1-2mm

Bio-oil from stalk by fast pyrolysis (National Natural Science Foundation of China , Coordinated by Prof.Liu Ronghou, Biomass Energy Lab. SJTU)

*Effect of hot vapor filtration on the characterization of bio-oil from rice husks with fast pyrolysis in a fluidized-bed reactor



Yield and physicochemical properties of bio-oil at condenser

Yield and physicochemical properties of the bio-oil at the condenser and the EP.

	C_1[c]	C_2[c]	F_1[c]	F_2[c]
Water content(wt.%)	64.41 ± 0.16	10.77 ± 0.10	75.09 ± 0.42	9.19 ± 0.08
Yield of bio-oil (wt.%)	57.3	42.7	60.5	39.5
Ratio of collected water content of oil[a]	88.9	11.1	92.7	7.3
C (wt.%)	17.07	60.95	10.67	66.56
H (wt.%)	10.76	7.26	11.23	7.50
N (wt.%)	<0.3	0.94	<0.3	1.30
O[b] (wt.%)	71.87	30.85	77.80	24.65
pH	2.84	4.10	3.37	4.40
Density (g/cm^3)	1.0705	1.1550	1.0392	1.1766
High heating value (MJ/kg)	–	22.06	–	23.86
Na content (ppm)	46	38	19	36
K content (ppm)	19	116	13	41
Ca content (ppm)	82	60	57	23
Mg content (ppm)	8	8	8	1

[a] The total water yield during the reaction process is equal to the sum of the product of mass and water content at each condenser. The ratio of the collected water content of oil for each condenser is equal to the collected water yield at each condenser divided by the total water yield.

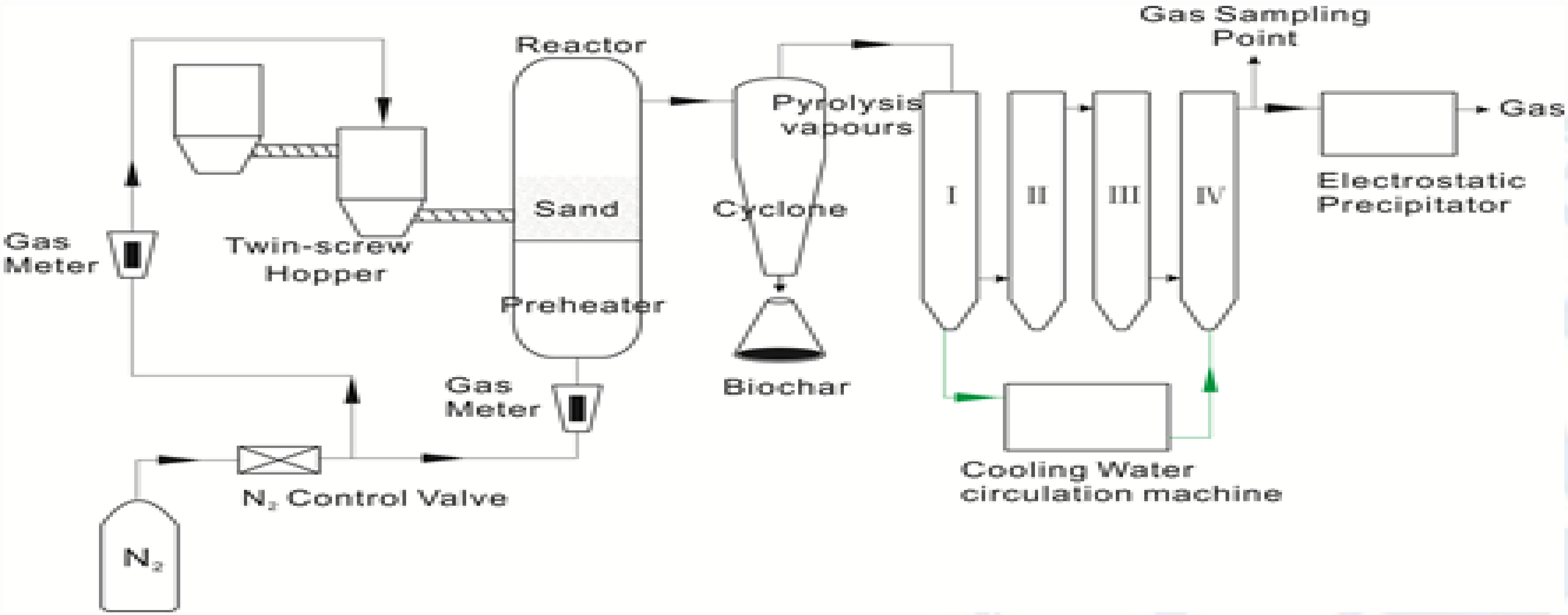
[b] By difference.

[c] C_1, C_2 were the bio-oil condensed in the condenser and EP when using the cyclone only to remove the solid particle, and F_1, F_2 were the bio-oil condensed in the condenser and EP when using the cyclone coupled with HVF.

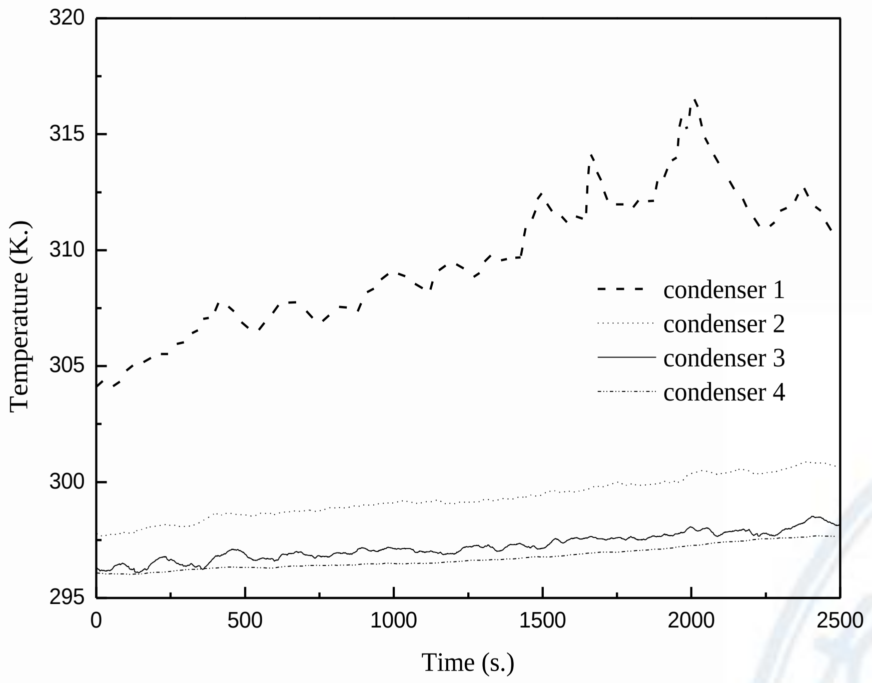
Conclusion:

It was found that the total bio-oil yield decreased and that the bio-oil has a higher water content, higher pH value, and lower alkali metal content when a HVF is used in the system.

*Effect of Selective Condensation on the Characterization of Bio-oil from Pine Sawdust Fast Pyrolysis Using a Fluidized-Bed Reactor



The flow chart of the fluidized bed reactor fast pyrolysis system



The temperature changes of the four condensers

Results

(1) Yield and the Water Content of the Bio-oil at Different Condensers

Yield and the Water Content of the Bio-oil at Different Condensers

	Condenser 1#	Condenser 2#	Condenser 3#	Condenser 4#	Condenser 5#
Yield of bio-oil **(wt/%)**	65.3	1.8	1.2	11.3	20.4
Water content**(wt/%)**	33.21	7.82	7.45	7.35	7.45
Ratio of collected water content of oil [a]	86.2	0.6	0.4	3.3	9.5

Note: [a] The total water yield during the reaction process was equal to the sum of the product of mass and water content at each condenser. The ratio of the collected water content of oil for each condenser is equal to the collected water yield at each condenser divided by the total water yield .

Conclusion 1 : The total bio-oil, the gases and the char yields were 41.5%, 43.3%, 15.2% respectively ;
and 86.2 wt % water steam was condensed in condenser 1.

(2) Other properties

pH Value of the Bio-oil

	1#	2#	3#	4#	5#
pH	2.66	2.73	2.78	2.78	2.78

Higher Heating Value (HHV) of the Bio-oil

	1#	2#	3#	4#	5#
HHV **(MJ/Kg)**	14.9	22.6	22.9	22.7	23.5

The Effect of Temperature on the Viscosity of Bio-oil

	20 ℃	30 ℃	40 ℃	50 ℃	60 ℃	70 ℃	80 ℃	90 ℃
Viscosity of bio-oil 1# **(mm^2/s)**	9.10	1.95	1.35	1.21	0.94	0.63	0.54	0.53
Viscosity of bio-oil 4# **(mm^2/s)**	938.13	326.09	142.38	69.25	38.01	12.93	7.26	5.80
Viscosity of bio-oil 5# **(mm^2/s)**	1210.97	397.44	175.48	82.50	46.87	26.88	17.48	12.62

Conclusion 2: The bio-oil condensed in the later condensers has a lower water content, higher pH value, higher heating value, higher kinetic viscosity compared to the first one.

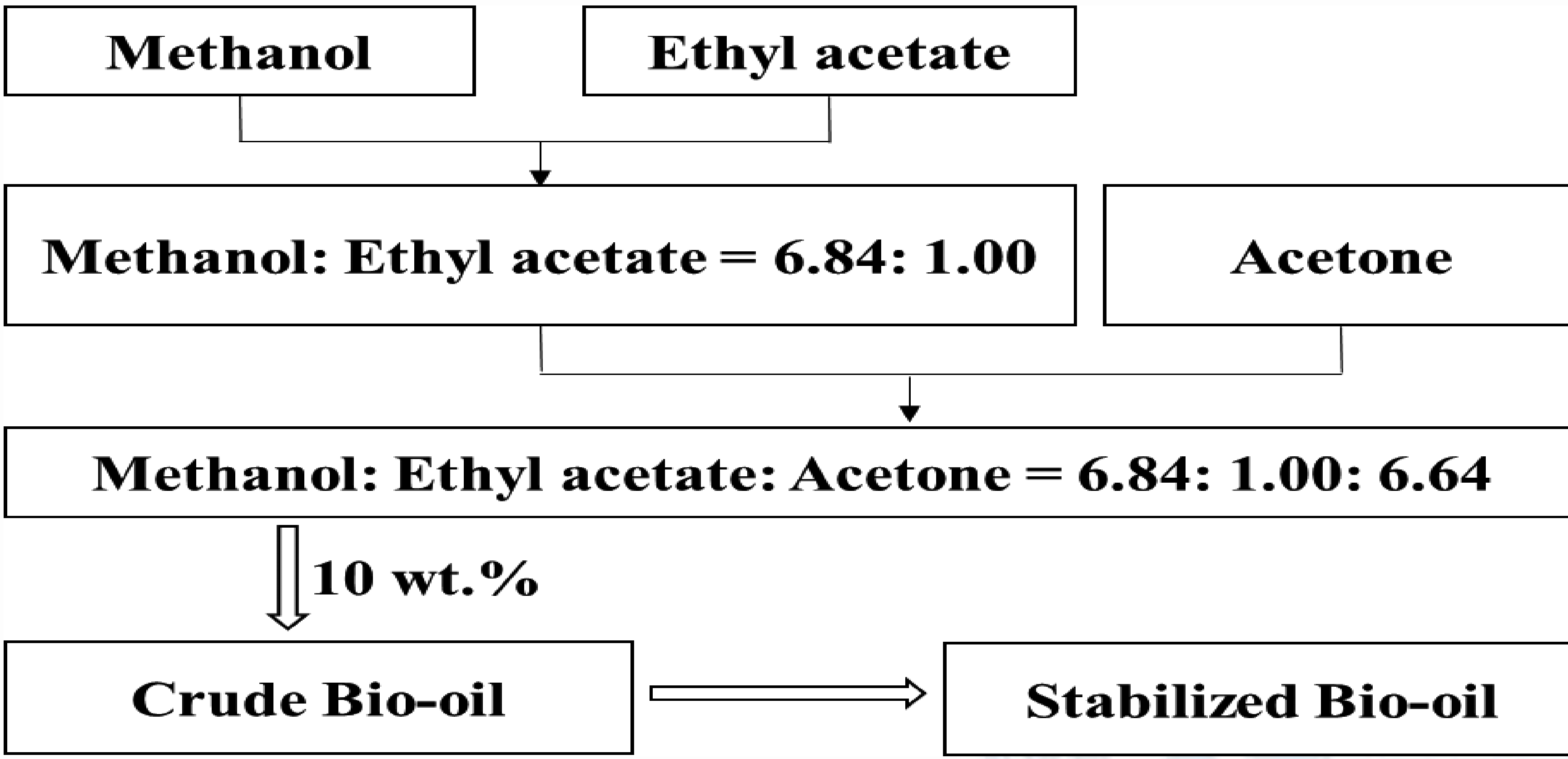
(3) GC-MS Results

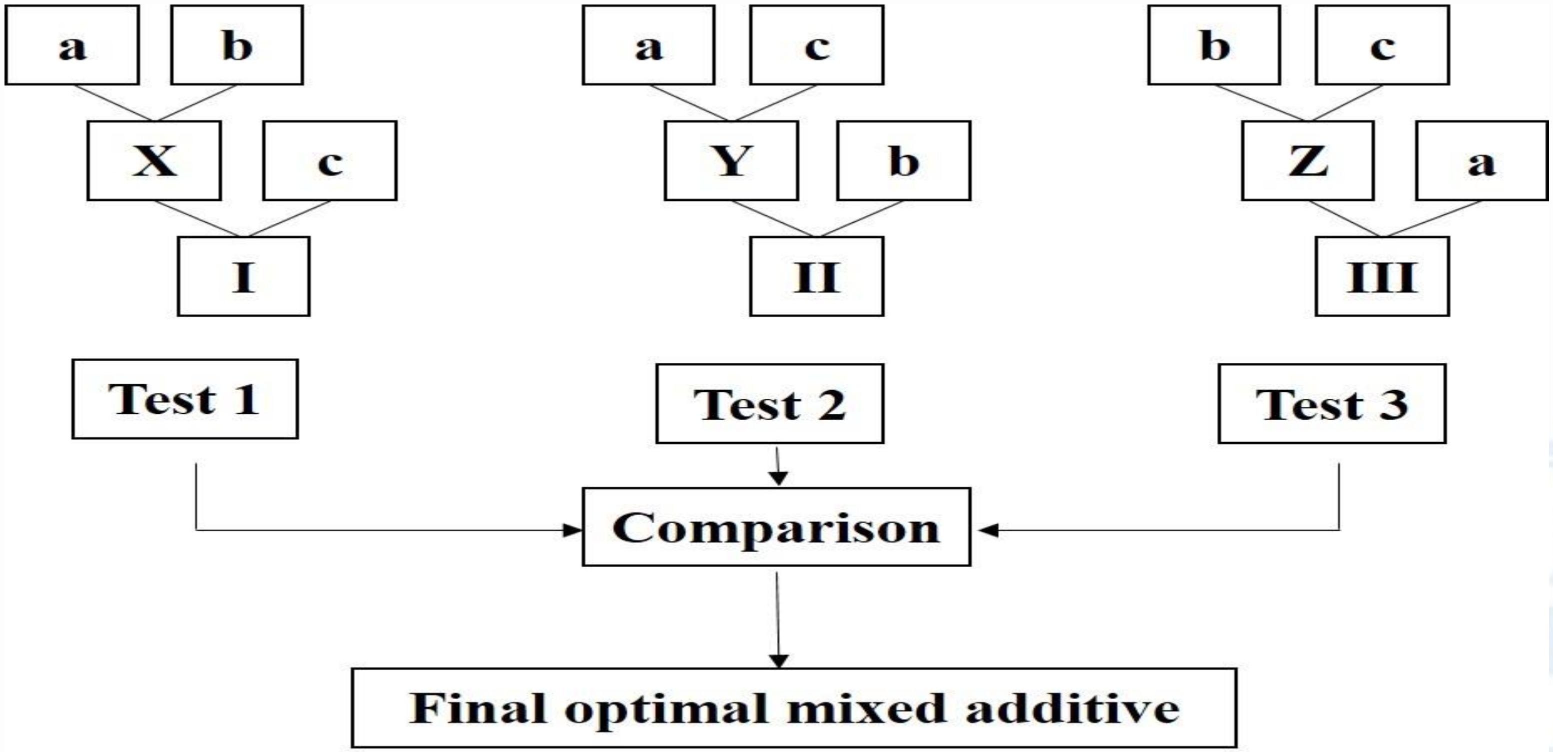
Table 8. Components of Bio-oil from Pine Sawdust Pyrolysis and Their Relative Mass Contents Detected by GC-MS

				Relative mass content (%)		
Peak NO.	Main identified compounds	RTA(min)	mol mass	1#	4#	5#
1	Ethynyl isopropyl ketone	3.552	96	0.15		
2	1,3-dione-4-Cyclopentene	3.642	96	1.21	0.21	0.2
3	Cyclopentanone	3.883	84	4.98		
4	2(5H)-Furanone	3.896	84		3.5	2.67
5	2-Methyl-2-cyclopentenone	4.124	96	3.92	1.41	1.24
6	1-(2-furanyl)-Ethanone,	4.227	110	1.18	0.32	0.38
7	3-methyl- 2,4-Pentanedione	4.314	114		0.27	
8	3-methyl- 2,5-Furandione	4.308	112	0.73		0.45
9	2-methyl-Cyclopentanone	4.448	98	9.98	6.68	6.11
10	Bicyclo[3.1.0]hexan-2-one	4.5	96			0.24

Conclusion 2: GC-MS showed that 102 types of chemical compounds were detected and most of the compounds were condensed at different condensers. The selective condensation is useful to separate the water and chemical compounds from bio-oil compared with direct contacting condensing.

*Optimization of a Mixed Additive and its Effect on Physicochemical Properties of Bio-Oil

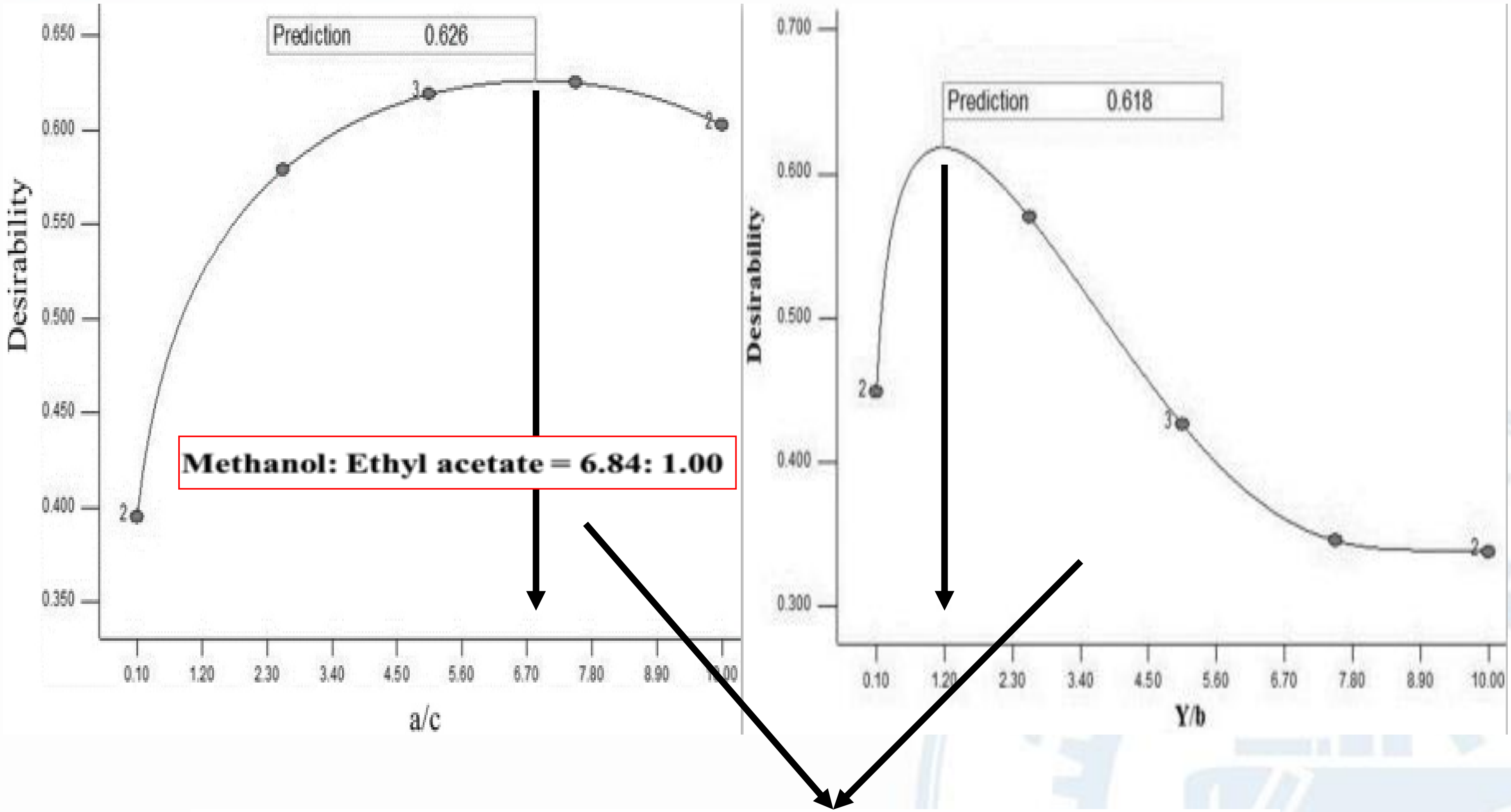




The diagram of the whole optimization experiment

a	methanol
b	acetone
c	ethyl acetate

Results of Test 2



Methanol: Ethyl acetate: Acetone = 6.84: 1.00: 6.64

Optimization curves of the proportion of (1) a to c and (2) Y to b

Project Title: Development of Equipment for Biomass Fast Pyrolysis for Bio-oil Production and its Demonstration in Thousand Ton Scale

Organizer: Shanghai JiaoTong University

Partners:1) Zhejiang University

2)Shandong University of Technology

3)Guangzhou Institute of Energy Conversion, Chinese Academy of Science

4)University of Science and Technology of China

5) University of Science and Technology of South China

6)Liaoyang Hengxing Company Ltd

Coordinator of the project: Ronghou Liu

Period: January 2011-December 2013

Budget from MOST: 11.76 Million RMB Yuan

A demonstration plant of biomass fast pyrolysis with bio-oil yield:10000 t/a in Shaanxi has been jointly built by Shanxi Yingjiliang Company and Shanghai Jiao Tong University, China

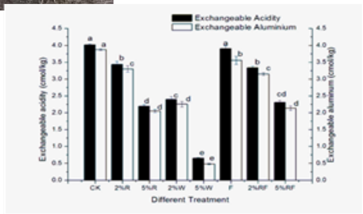
4.Biochar Application for Soil Amendment

-863 Project by MOST

1)Developed a biochar application machine:

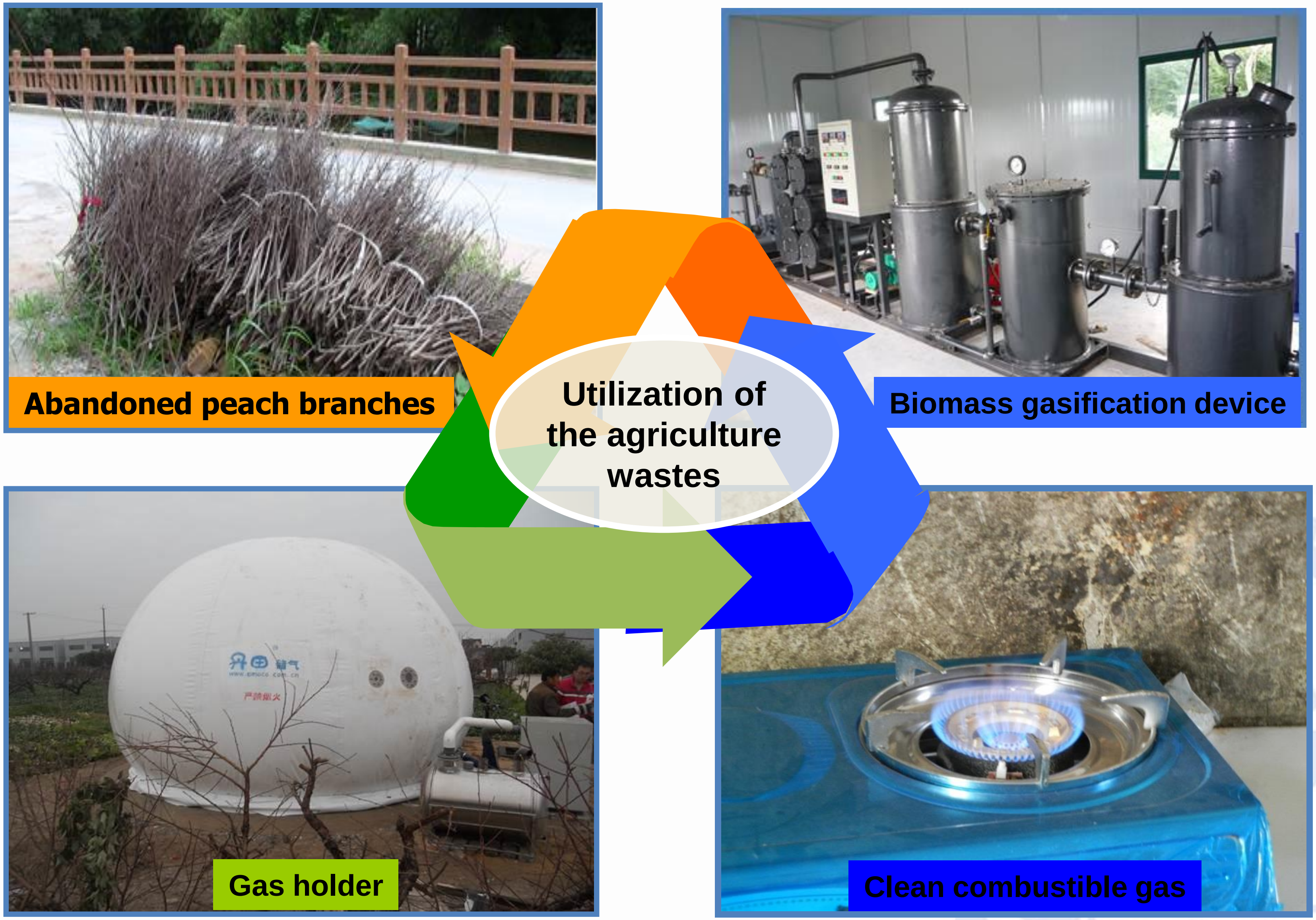
Scale4753.8-34185.2 kg/h

2) The effect of biochar on soil and plant growth



wood sawdust biochar could reduce the exchangeable acidity and aluminum by 84% and 88%, respectively at the 5% biochar amendment level.

5.Biomass gasification



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6.Bioethanol

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Bioresource Technology 99 (2008) 847–854
BIORESOURCE TECHNOLOGY

Impacts of main factors on bioethanol fermentation from stalk juice of sweet sorghum by immobilized *Saccharomyces cerevisiae* (CICC 1308)

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Received 17 October 2006; received in revised form 17 January 2007; accepted 17 January 2007
Available online 13 March 2007

Abstract

In order to attain a higher ethanol yield and faster ethanol fermentation rate, orthogonal experiments of ethanol fermentation with immobilized yeast from stalk juice of sweet sorghum were carried out in the shaking flasks to investigate the effect of main factors, namely, fermentation temperature, agitation rate, particles stuffing rate and pH on ethanol yield and CO_2 weight loss rate. The range analysis and analysis of variance (ANOVA) were applied for the results of orthogonal experiments. Results showed that the optimal condition for bioethanol fermentation should be $A_4B_3C_3D_4$, namely, fermentation temperature, agitation rate, particles stuffing rate and pH were 37 °C, 200 rpm, 25% and 5.0, respectively. The verification experiments were carried out in shaking flasks and 5 L bioreactor at the corresponding parameters. The results of verification experiments in the shaking flasks showed that ethanol yield and CO_2 weight loss

This paper has been Top 20 Articles, in the Domain of Article 17360181, Since its Publication (2008)

1. Introduction

Ethanol production as an alternative fuel energy resource has been a subject of great interest since the oil crisis of the 1970s (Tao et al., 2005). Therefore, a strong need exists for efficient ethanol production with low cost in raw material and production process. The varied raw materials used in the production of ethanol via fermentation are conveniently classified into three main types of raw materials: sugars, starches, and cellulose materials. Sugars (from sugarcane, sugar beets, sweet sorghum, molasses, and fruits) can be converted into ethanol directly. Starches (from corn, cassava, potatoes, and root crops) must firstly be hydrolyzed to fermentable sugars by the action of enzymes from malt or molds. Cellulose (from wood, agricultural residues, waste sulfite liquor from pulp, and paper mills) must likewise be converted into sugars, generally by the action of mineral acids. Once simple sugars are formed, enzymes from microorganisms can readily ferment them to ethanol (Lin and Tanaka, 2006). As for materials, one of the prime sources being investigated for ethanol is sweet sorghum. Sweet sorghum {*Sorghum biocolor* (L.) Moench} is a high biomass- and sugar-yielding crops (Bryan, 1990), meantime, the stalk of sweet sorghum contains quite a few quantities of soluble (glucose and sucrose) and insoluble carbohydrates (cellulose and hemicellulose) (Jasberg et al., 1983). Therefore, of many crops currently being investigated for energy and industry, sweet sorghum is one of the most promising, particularly for ethanol production (Gnansounou et al., 2005).

The advantages of immobilized cells over free cell sys-

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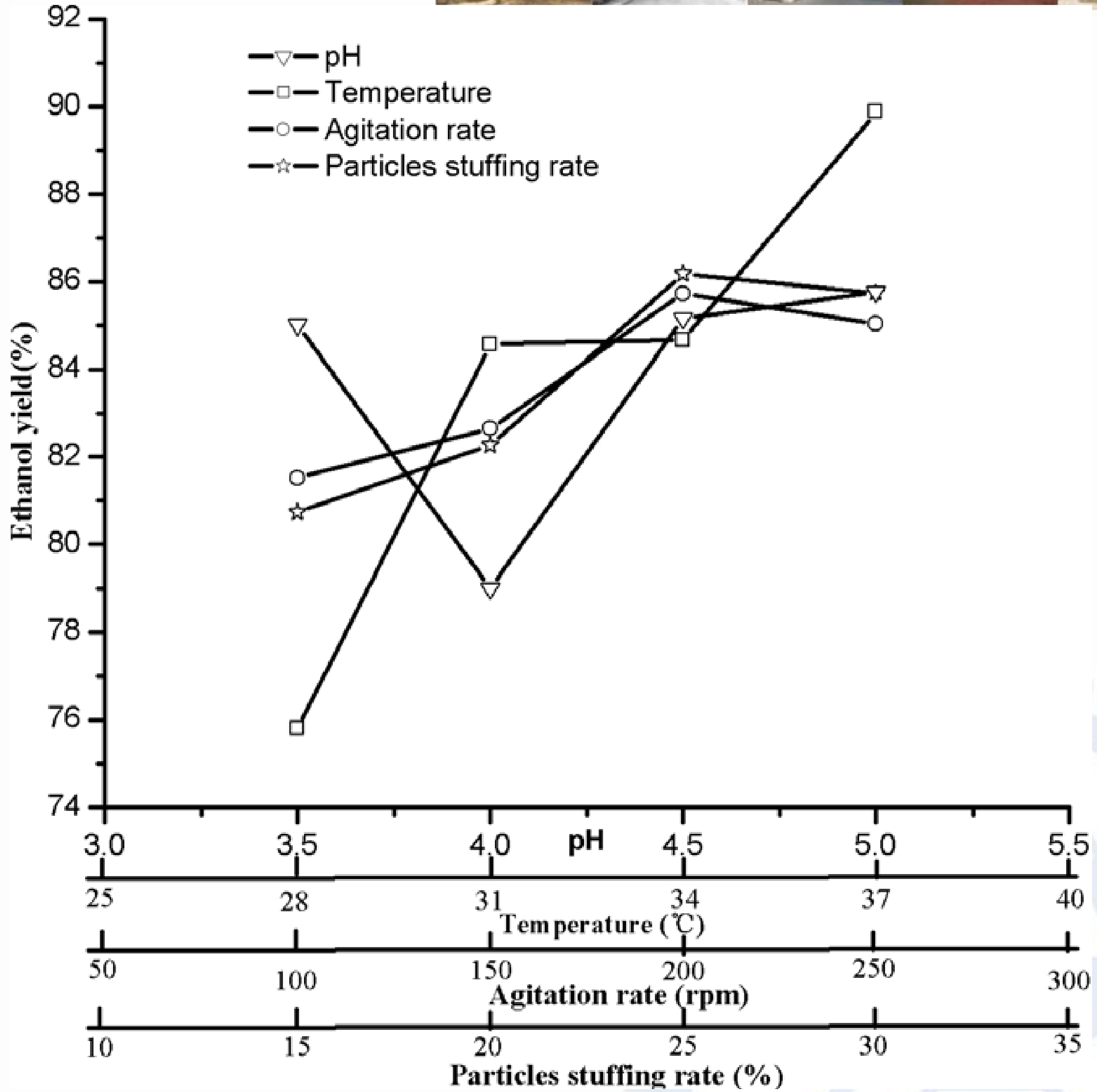
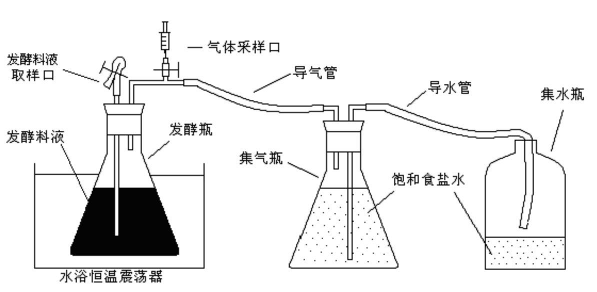
Optimal condition for bioethanol fermentation:

**Fermentation temperature:37 ° C , agitation rate 200 rpm, particles stuffing rate:25%, pH 5.0.
Ethanol yiedl:98.07%, Fermentation time 11**

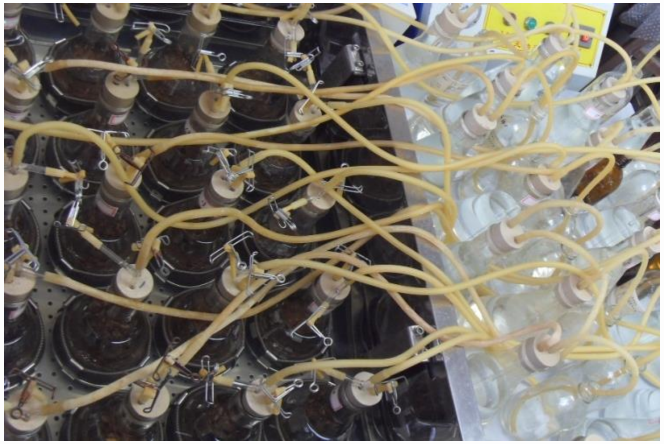
h.



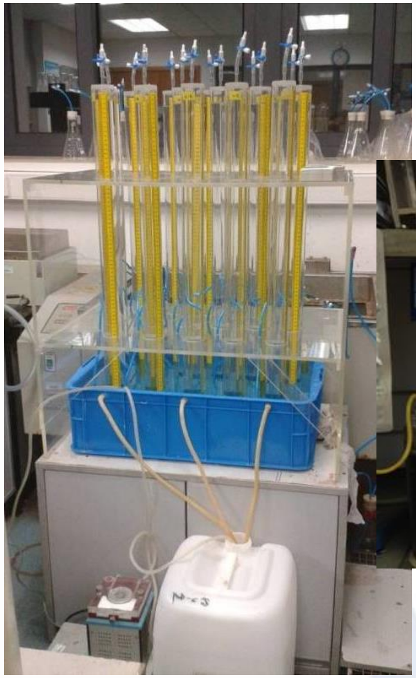
7.Biogas



Fermentation device design



BMP Test device and CSTR Reactor



Experimental apparatus

energy&fuels Article
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Impacts of Alkaline Hydrogen Peroxide Pretreatment on Chemical Composition and Biochemical Methane Potential of Agricultural Crop Stalks

Chen Sun,[†,‡,§] Ronghou Liu,[*,†,§] Weixing Cao,[§] Renzhan Yin,[∥] Yuanfei Mei,[†,‡,§] and Le Zhang[†,§]


energy&fuels
Impacts of Alkaline Hydrogen Peroxide Pretreatment on Chemical Composition and Biochemical Methane Potential of Agricultural Crop Stalks

Objective:

to increase bio-digestibility and methane yield from crop residues via pretreatment

Results and conclusions:

The AHP pretreatment could:

- break down esterified and etherified linkage in lignocellulose
- recover 90% of glucose and 80% of xylose;
- remove 30-50% of lignin;
- increased methane yield and bio-digestibility for certain biomass

It is necessary to utilize of the liquid waste from the pretreatment.

Selected Publications(SCI)

1) Tianju Chen, Ceng Wu, Ronghou Liu, et al. Effect of hot vapor filtration on the characterization of bio-oil from rice husks with fast pyrolysis in a fluidized bed reactor[J]. Bioresource Technology, 2011, 102, 6178-6185.

2) Tianju Chen, Chunjian Deng, and Ronghou Liu. Effect of Selective Condensation on the Characterization of Bio-oil from Pine Sawdust Fast Pyrolysis Using a Fluidized-Bed Reactor [J]. Energy & Fuels, 2010, 24 (12), pp 6616–6623.

3) Tianju Chen, Ceng Wu, Ronghou Liu. Steam reforming of bio-oil from rice husks fast pyrolysis for hydrogen production[J]. Bioresource Technology, 2011, 102, 9236-9240.

4) Ronghou Liu, Fei Shen. Impacts of main factors on bioethanol fermentation from stalk juice of sweet sorghum by immobilized Saccharomyces cerevisiae (CiCC 1308)[J]. Bioresource Technology, 2008, 99, 847-854.

5) Le Zhang, Ronghou Liu, Renzhan Yin, Yuanfei Mei.Upgrading of bio-oil from biomass fast pyrolysis in China: A review[J].Renewable and Sustainable Energy Reviews 24 (2013) 66–72.

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6） ~~Renzhan Yin, Ronghou Liu~~, Yuanfei Mei, Wenting Fei, Xingquan Sun. Characterization of bio-oil and bio-char obtained from sweet sorghum bagasse fast pyrolysis with fractional condensers[J]. Fuel, Volume 112, October 2013, Pages 96–104.

7） Ceng Wu, Ronghou Liu. Sustainable hydrogen production from steam reforming of bio-oil model compound based on carbon deposition/elimination[J]. International Journal of Hydrogen Energy, 2011, 36, 2860-2868.

8）Ceng Wu, Ronghou Liu. Carbon deposition behavior in steam reforming of bio-oil model compound for hydrogen production[J]. International Journal of Hydrogen Energy, 2010, 35, 7386-7399.

9）Weixing Cao, Chen Sun, Ronghou Liu, Renzhan Yin, Xiaowu Wu. Comparison of the effects of five pretreatment methods on enhancing the enzymatic digestibility and ethanol production from sweet sorghum bagasse[J]. Bioresource Technology, Volume 111, May 2012, Pages 215–221.

10） Renzhan Yin, Ronghou Liu, Jinkai Wu, Xiaowu Wu, Chen Sun, Ceng Wu. Influence of particle size on performance of a pilot-scale fixed-bed gasification system[J]. *Bioresour*ce Technology, 119 (2012) 15–21.

8.Conclusion

Different conversion technologies can treat different types of raw materials, and different product can be obtained, there are both advantages and disadvantages for any conversion technology. Therefore, adequate conversion technology should be chosen according to concrete conditions in order to promote commercialization of biomass energy.

Thank you！