



Gasification Conversion and Char Reactivity of Rubber Seed Shell and High Density Polyethylene Mixtures using Steam Co-Gasification Process

Bridgid L. F. Chin^a, Suzana Yusup^{*a}, Ahmed Al Shoaibi^b, Pravin Kannan^b, Chandrasekar Srinivasakannan^b, Shaharin A. Sulaiman^c

^aBiomass Processing Lab, Centre for Biofuel and Biochemical Research, Green Technology MOR, Department of Chemical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh 31750, Malaysia

^bThe Petroleum Institute, P. O. Box 2533, Abu Dhabi, United Arab Emirates

^cDepartment of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Tronoh 31750, Malaysia
drsuzana_yusuf@petronas.com.my

Due to the recent surge of global energy demand and the fear of climate change, an extensive attention from worldwide in seeking for cleaner alternative means of renewable energy and this has been a topic of interest widely. With the abundance supply of biomass and plastic waste generated annually and finding an effective method in utilizing these wastes, leads to a notion of using these wastes in the co-gasification process. Although there are studies on co-gasification of biomass and waste mixtures, limited studies focused on the understanding of the char reactivity and gasification conversion of this mixture. Hence, an experimental study on steam co-gasification of rubber seed shell and high density polyethylene mixtures in argon atmosphere is carried out using thermogravimetric (TGA) approach under non-isothermal condition. This work presents the surface physical morphology of rubber seed shell (RSS), high density polyethylene (HDPE), and its mixtures. Furthermore, the char conversion and char reactivity of RSS, HDPE, and their mixtures at different proportions are investigated in both pyrolysis and gasification process. The argon gas is supplied at a flowrate of 100 mL min⁻¹ and the steam is generated from superheater at 383 K whilst injected at flowrate of 3000 µL h⁻¹ into the TGA system.

1. Introduction

Co-gasification of biomass and plastic waste mixtures is defined as a chemical process that converts plastic and biomass waste into gases such as H₂, CO, and CH₄ that possess useable heating value in an oxygen deprived environment using air, oxygen, steam, carbon dioxide or a combination of these at temperature exceeding 700 °C for applications such as power generation through gas turbines, production of liquid fuels using Fischer Tropsch synthesis, and production of ethanol, methanol, and hydrogen (Safitri, 2005).

Although coal gasification chemistry is well established and it has been implemented for biomass gasification, however, the understanding of the char reactivity and char conversion of co-gasification of plastic-biomass mixtures has not been widely studied. Moghadam et al. (2013) examined the binary mixtures of palm kernel shell and polyethylene (PE) waste using catalytic steam gasification in pilot scale fluidized bed gasifier on the hydrogen production. Pinto et al. (2002) investigated the steam co-gasification of pine and PE waste mixtures in a fluidized bed on the process conversion and gas composition. Ahmed et al. (2011) studied on the steam co-gasification of PE and woodchip mixtures in a semi-batch reactor on the syngas yield, hydrogen yield, energy yield, apparent thermal efficiency, and carbon yield. Wilk and Hofbauer (2013) investigated the steam co-gasification of different types of plastics (plastics from municipal solid waste, plastics from automotive shredder residues, PE regrind, and pure PE) with soft wood pellets in a dual fluidized bed steam gasifier (DFB) on the product gas, and tar formation.

Table 1: Characteristics of RSS and HDPE waste

Sample	Ultimate analysis (wt%, dry ash basis)					Ultimate analysis (wt%, dry basis)			
	C	H	N	S	O	Moisture Content	Volatile Matter	Fixed Carbon	Ash
RSS	44.31	4.38	0.51	0.13	50.67	8.59	80.98	6.62	3.81
HDPE	81.45	12.06	0.34	0.79	5.36	0.00	99.46	0.00	0.34

The present work investigates the char conversion and char reactivity of RSS, HDPE, and their mixtures at different proportions (20/80, 40/60, and 80/20 weight ratio of HDPE/RSS) in both pyrolysis and gasification process.

2. Experimental

2.1 Materials and Sample Preparation

The raw materials used in this work are RSS from Vegpro Trading, Malaysia and HDPE plastic from Shen Foong Plastic Industries Sdn Bhd, Malaysia. These materials are ground and sieved to a particle size of $\leq 710 \mu\text{m}$ fractions. Homogenized HDPE/RSS blends in respective weight ratio are prepared. The characteristics of the materials used in this study are presented in Table 1. The ultimate and proximate analysis of the HDPE and RSS are conducted in LECO CHNS-932 elemental analyser and thermogravimetry analyser EXSTAR TG/DTA 6300 (Seiko Instrument Inc.) respectively.

2.2 Experimental Apparatus and Procedure

The experiments are performed using thermogravimetric analyser EXSTAR TG/DTA 6300 (Seiko Instrument Inc.) as illustrated in Figure 1. Approximately 5 mg of sample is placed on a ceramic crucible in TGA under an inert atmosphere of argon. A flow rate of 100 mL min^{-1} of argon gas is fed into the system for 20 min at a temperature of 323 K. Subsequently, all samples are heated from 323 K to 1173 K at respective heating rates and temperatures are kept constant at 10 minutes. During heating, the TGA is used to measure mass variation of the materials and furnace temperature. Steam is generated by a superheater at 383 K and is injected into the TGA at a flowrate of $3000 \mu\text{L h}^{-1}$ when the temperature inside the TGA equipment reached to 383 K to avoid any occurrence of condensation within the system. The equivalence ratio for the gasification process is 0.25. All experiments are repeated two or three times.

3. Theory

Gasification and pyrolysis reactivity, r of the char is defined as the char conversion per unit time relative to the actual mass of the sample (m) at the given time:

$$r = \frac{1}{m} \frac{dm}{dt} = \frac{1}{1-X} \frac{dX}{dt} \quad (1)$$

Char conversion rate, X is defined as the normalized form of weight loss data of decomposed sample as shown by the following expression:

$$X = 1 - \frac{m}{m_i} \quad (2)$$

where m is the actual mass of the sample at the given time and m_i is the initial mass of the sample.

4. Results and Discussion

4.1 Morphology of Rubber Seed Shell (RSS) and High Density Polyethylene (HDPE)

Figure 2(a) and 2(b) shows the field emission scanning electron microscopic (FESEM) images of the external surface for RSS and HDPE respectively. The FESEM images of these samples are determined using Zeiss Supra 55 VP. The magnification of $1000\times$ and $100\times$ is used to capture the FESEM images for RSS and HDPE respectively. For the RSS, the external surface is abit rough with pores exists on the surface. Meanwhile, an amorphous surface is observed in the HDPE with no pores appearing on its surface.

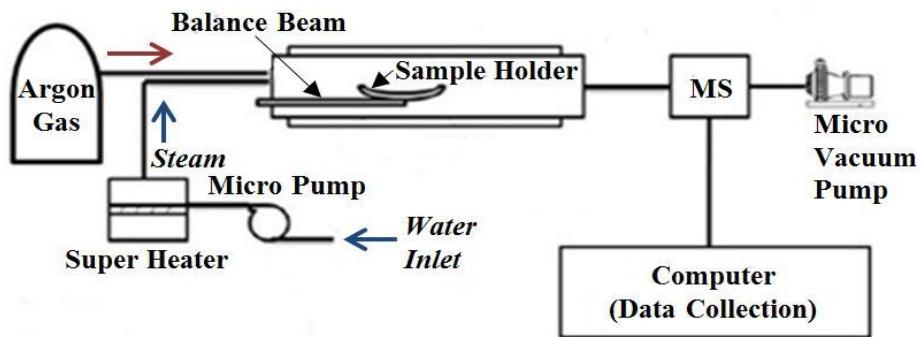


Figure 1: Experimental setup of TGA-MS

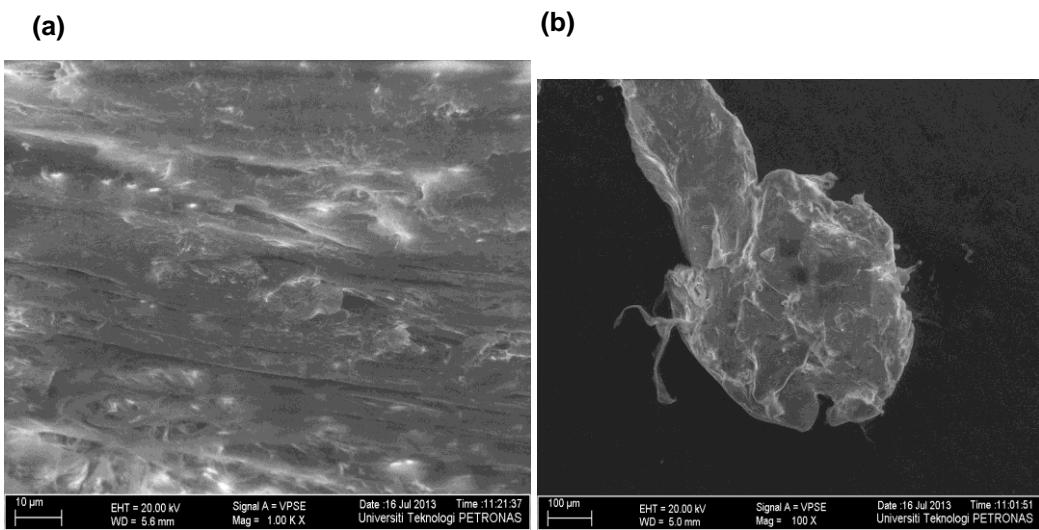


Figure 2: The field emission scanning electron microscopic (FESEM) images of surface (a) RSS (b) HDPE.

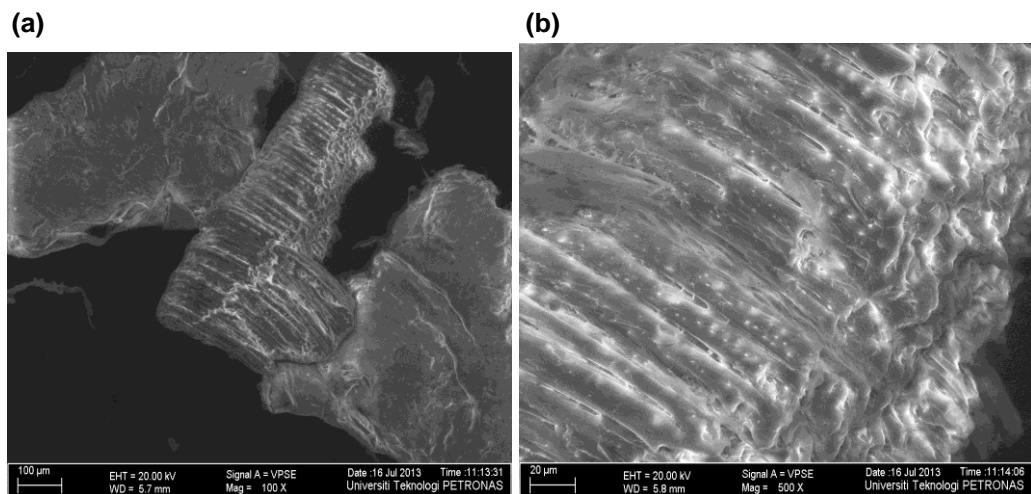


Figure 3: The field emission scanning electron microscopic (FESEM) images of surface of HDPE/RSS mixtures (0.2/0.8 weight ratio) in magnification of (a) 100 \times and (b) 500 \times

Figure 3(a) and (b) displays the FESEM images of HDPE/RSS mixtures in the ratio of 0.2/0.8 with a magnification of 100 \times and 500 \times respectively. It is observed the external surface of the HDPE/RSS mixture is rough. Furthermore, it can be seen that the distribution of the individual particles of HDPE and RSS is said to be consistent in the mixture after manually mixing for 5 min.

4.2 Char reactivity on the HDPE, RSS, and mixtures of HDPE and RSS mixtures

Figure 4 and 5 illustrates the reactivity versus char conversion for pyrolysis and gasification process respectively in RSS, HDPE, and RSS/HDPE mixtures in different weight proportions of 0.2/0.8, 0.4/0.6, and 0.6/0.4. For HDPE, the char reactivity increases significantly throughout the range of char conversion when compared to RSS, and RSS/HDPE mixtures. And also, it is observed that the RSS and RSS/HDPE mixtures depict similar char reactivity behaviour with char conversion regardless of the processes involved. Based on Figures 4 and 5, the char reactivity increases significantly from 0 to 0.080 and 0 to 0.100 respectively for pyrolysis and gasification process as the char conversion increases from 0 to 0.1. The char reactivity for all the samples except HDPE remained relatively constant as char conversion increases from 0.1 to 0.8 in both processes. It is also observed that the char reactivity of the gasification is much higher compared to pyrolysis process in respect to char conversion. This is evidently shown in Table 2 which summarized the char reactivity and char conversion for RSS, HDPE, and RSS/HDPE mixtures in pyrolysis and gasification process. This is because gasification process accelerates the conversion of solid to gaseous products compared to pyrolysis process

Table 2: Comparison of char reactivity and char conversion for RSS, HDPE, and RSS/HDPE mixtures in pyrolysis and gasification process

Sample	Conversion, X	Pyrolysis	Gasification
		Char Reactivity, r (min^{-1})	
RSS	0.2	0.072	0.103
	0.4	0.065	0.109
	0.6	0.043	0.102
	0.8	0.040	0.098
HDPE	0.2	0.056	0.101
	0.4	0.070	0.133
	0.6	0.102	0.212
	0.8	0.153	0.306
RSS/HDPE (0.2/0.8 weight ratio)	0.2	0.055	0.102
	0.4	0.052	0.113
	0.6	0.052	0.126
	0.8	0.051	0.157
RSS/HDPE (0.4/0.6 weight ratio)	0.2	0.074	0.119
	0.4	0.709	0.128
	0.6	0.079	0.120
	0.8	0.080	0.132
RSS/HDPE (0.8/0.2 weight ratio)	0.2	0.080	0.145
	0.4	0.081	0.117
	0.6	0.057	0.096
	0.8	0.046	0.083

5. Conclusion

In the present work, the char reactivity versus char conversion for RSS, HDPE, and RSS/HDPE mixtures are investigated. In addition, the surface morphology for these samples are also presented. It is found that RSS and RSS/HDPE mixtures shows almost similar behaviour regardless of the processes involved. The char reactivity of these samples are found to be much higher in gasification process compared to pyrolysis process. This is due to the acceleration of the conversion of solid to gaseous products in gasification process is much higher compared to pyrolysis process.

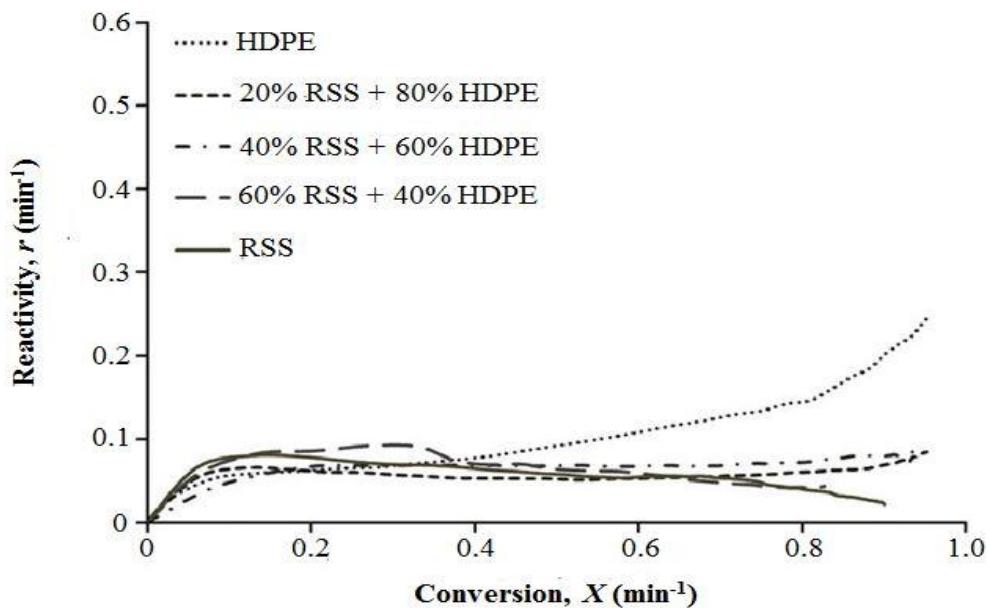


Figure 4: Pyrolysis reactivity versus char conversion rate

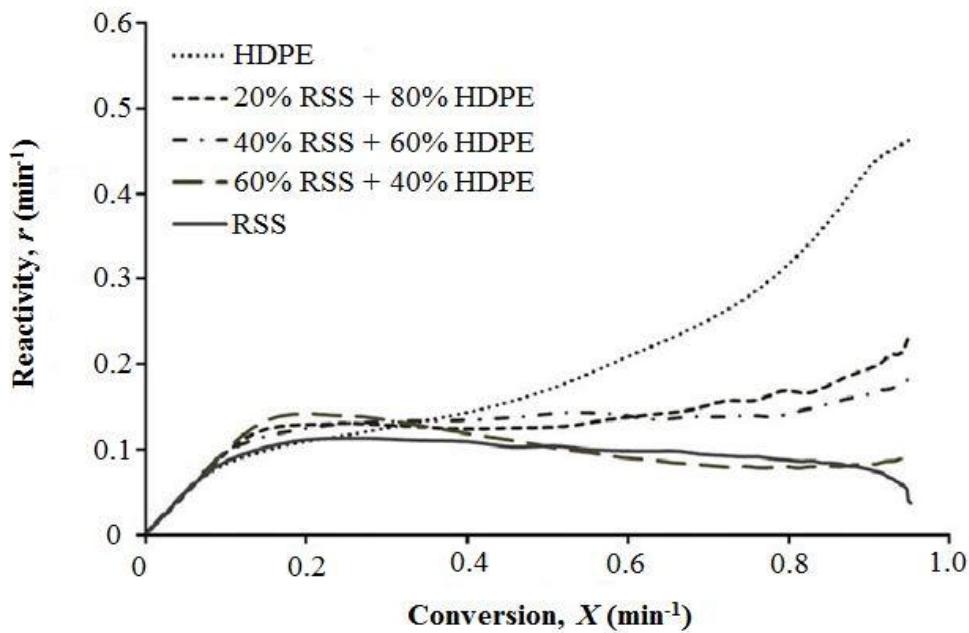


Figure 5: Gasification reactivity versus char conversion rate

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References

- Ahmed I.I., Nipattummakul N., Gupta A.K., 2011, Characteristics of syngas from co-gasification of polyethylene and woodchips, *Applied Energy*, 88, 165-174, DOI: 10.1016/j.apenergy.2010.07.007.
- Moghadam R.A., Yusup S., Lam H.L., Al Shoaibi A., Ahmad M.M., 2013, Hydrogen production from mixture of biomass and polyethylene waste in fluidized bed catalytic steam co-gasification process, *Chemical Engineering Transactions*, 35, 565-570, DOI: 10.3303/CET1335094.
- Pinto F., Franco C., André R.N., Miranda M., Gulyurtlu I., Cabrita I., 2002, Co-gasification study of biomass mixed with plastic wastes. *Fuel*, 81(3), 291-297, DOI: 10.1016/s0016-2361(01)00164-8.
- Safitri A., 2005, Biomass gasification using bubbling fluidized bed-gasifier: investigation of the effect of different catalysts on tar reduction, MSc Dissertation, Chemical Engineering and Chemistry, Technische Universiteit Eindhoven, The Netherlands.
- Wilk V., Hofbauer H., 2013, Co-gasification of plastics and biomass in a dual fluidized-bed steam gasifier: possible interactions of fuels. *Energy Fuels*, 27(6), 3261-3273, DOI: 10.1021/ef400349k.