International Journal of Emerging Technology and Advanced Engineering
Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 131-138
An ISO 9001:2008 certified Int. Journal, ISSN 2250-2459, available online at www.ijetae.com

STUDIES ON THE CO-COMBUSTION BEHAVIOUR OF COAL/BIOMASS BLENDS USING THERMOGRAVIMETRIC ANALYSIS

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ABSTRACT

In relation to future energy demand and fossil fuel crisis particularly in India, biomass is gaining its importance for possible utilization as co-fuel. This study focuses the use of 'low temperature biomass char' instead of raw biomass in the blends to extract some specific advantages like lowering of grinding energy, intensification of heat energy, proper adjustment of 'VM and fuel ratio' etc. In the present investigation corn cob char and saw dust char were examined for their possible use in co-combustion with a typical high ash Indian coal. Combustion behaviour of different binary blends of 'coal and biomass chars' were examined in detail with the help of simultaneous DSC/TGA (Differential Scanning Calorimetry/Thermogravimetric Analyser) instrument. Characteristic combustion parameters of parent coal, biomass char and their blends were compared. Kinetic parameters for the combustion of all the blend samples were evaluated in the defined burning zone. Deviation of the experimentally observed burning rate curves from theoretically evaluated rate pattern for all the blends have been shown in this paper and synergistic effects of co-combustion were highlighted which signifies improvement of reactivity. Lowering of activation energy in major combustion zone was also observed for the coal/ biomass char blends in most of the cases. On overall basis, this study reflects the improvement of combustion performance with the increase in proportion of biomass char. As a matter of fact such study helps in the process of the identification potential blend-combination and selection of blend proportion to derive some specific advantages with respect to particular combustion practice.

Keywords: Biomass; Co-combustion; Combustion; Biomass char; TGA

1. INTRODUCTION

All over the globe there is an increasing trend of co-combustion of biomass and coal for production of energy. Co-firing and co-gasification of fossil fuels and biomass (saw dust, rice husk, coconut coir, straw, corn-cob etc.) are presently being considered because partial replacement of precious fossil fuel is possible in such cases, which give extensive support to the growth of power sector in developing countries like India. The combustion of coal in presence of biomass is of great interest in respect of control of CO_2 emissions as biomass is considered to be carbon neutral. Additionally use of biomass can reduce emission of NO_x and SO_x. The world is facing technical challenges with co-combustion of biomass and coal in boilers designed for pulverized coal combustion. The one of the most vital technical issue is the uncertainties in combustion performance of coal-biomass blends which include 'carbon burn out' pattern, heat release pattern, kinetics, etc which seeks current attention particularly in Indian context. Co-combustion is possibly best energy option for the future power generation of India, where plenty of different kinds of biomass is available. Motivations to reduce CO_2 emissions, particularly in countries like India again strengthen the foundation of the rationality for co-combustion. [1-7]. As compared to coal, biomass fuels contain higher volatile matter with higher oxygen content and as such possibility of easy release of volatile matter in a combustor is more. All these characteristics of biomass have been found to have large influence on the burn out time of blends of coal and biomass. It has been observed that in co-combustion with fossil fuel, use of biomass chars may be a preferred option instead of raw biomass [8,9]. Kastanaki et. al [8] observed that biomass chars obtained after partial devolatilization are more reactive than those obtained from coals. Biomass chars were found to have porous and highly disordered carbon structure and belong to the class of most reactive carbon materials. The porosity within the chars causes more accessibility of the reactive gas like oxygen to active sites resulting in the very good combustion condition. [8,9]. Based on the emerging need, detailed investigations are felt necessary to examine the compatibility of different kind of biomass with coal and to select suitable blend composition(s) before utilizing those biomass products in utility operation as co-fuels. In this paper, it has been studied whether char blend kinetics can be predicted from the kinetic parameters for char/coal combustion. Theoretical rate curves for the blends based on DTG profiles of char and coal were considered in this study to see the deviation of the experimentally observed rate curve from the respective theoretical curve. Burning behaviour of the blends has also been examined with respect to conventional DSC-TGA parameters. Such studies may help to identify suitable blend combination as well as blend composition particularly in respect of co-combustion.

2. EXPERIMENTAL

2.1. Coal selection and sample preparation

For this study one high ash Indian coal and two numbers of biomass samples (saw dust and corn cob) were chosen as constituents for sample preparation. The coal sample was crushed to -3mm size at first and subsequently crushed to -212 micron size. Each of the biomass samples was pyrolysed at 300^{o}C (one hour) to obtain char samples. Char samples were pulverized to -212 micron size. Blend combinations were prepared using each of those low temperature chars and coal. Sawdust (SD) and corn cob (CC) chars were blended with single coal to prepare different binary blends with varying proportion biomass. Different blend composition have been selected as 90:10, 80:20, 70:30, 50:40, 30:50 which have been designated as BSD1, BSD2, BSD3, BSD4 and BSD5 and BC1, BC2, BC3, BC4 and BC5 for saw dust and corn cob respectively. All the blend samples, coal sample and char samples were further ground to -75 micron size for studying the combustion characteristics. Basis for choosing biomass char instead of raw biomass has been elaborated in our earlier study [10].

2.2. Chemical analysis

Proximate and ultimate analysis of samples were done using standard procedures i.e., IS: 1350 -Part-I: 1984, Part III: 1969, Part IV/1:1974, Part IV/2: 1975 and ASTM E871, D1102, E872. The gross calorific value (GCV) of coal was determined as per IS 1350 (Part 2): 1970. High heating value (HHV) of biomass samples was also determined by using formula HHV = (33.5C + 142.3H – 15.4O -14.5N)/100 [11] where C, H, N, O are in wt % dry ash free basis. The chemical parameters of the samples are shown in Table 1.

2.2. Thermal analysis, DSC/TGA/DTG

Combustion behavior of coal, biomass chars and their blend samples were studied with the help of simultaneous thermal analyzer, model STA 409C (NETZSCH, Germany). About 20 mg of sample was taken for this study. Samples were heated up to 750^{o}C at a constant heating rate of 10^{o}C/min, under a constant air flow rate of 50ml/min through the sample chamber. The thermograms were analyzed to determine the relevant combustion parameters like DSC peak temperature, DTG (differential thermogravimetry, first derivative of TG curve) peak temperatures, maximum rate of weight loss (R_{max}, %/min) which indicates the maximum reactivity attained in terms of rate of weight loss at DTG peak temperatures, initial temperature (*Ti*) which is the temperature where weight loss first reaches to 1%/min in DTG after initial moisture loss peak and burnout temperature (BOT) where weight loss reaches to 1%/min at the terminal phase of the DTG profile. The activation energy (E_{act}) of all the samples was determined by using NETZSCH Gerätebau thermo kinetics software following single step first order model. In order to investigate whether interaction occurred between the components of char blends a theoretical combustion rate curve was calculated based on the same temperature history of the two fuels. Theoretical rate curve was compared with experimentally observed rate curve. The TGA results are shown in Table 2.

3. RESULTS AND DISCUSSION:

Relevant combustion parameters (DSC-TGA experiments) of coal, biomass chars and blends of both the 'coal-biomass char' combinations have been presented in Table 2. Kinetic parameters (viz., activation energy and pre-exponential factor, correlation coefficient, etc.) of all the samples have also been incorporated in Table 2. Variation of different combustion parameters with change in blend composition as compared to expected weighted average values have been presented in Fig. 1(a-f). DTG peak temperature of the biomass samples was lower than that of coal which indicates biomass samples are more reactive than that of coal samples. As assessed from lowering of DTG peak temperatures for the blends, reactivity of blend samples is higher than the expected hike in reactivity to arise out of co-firing of biomass char with coal. Gradual increase in reactivity follows linear path with increase in proportion of biomass chars in blends, but the rate of increase is faster than that reflected from weighted average evaluation. Ti values of all the blend samples, irrespective of both the combinations, observed to be lower as compared to coal sample indicating earlier start of burning. Blends with saw dust char are non-additive with respect to Ti and DTG peak temperature which represents the characteristics at initial and in major combustion zone. To be more precise, these two parameters indicate synergistic effect up to major combustion zone. But from the terminal phase characteristics (i.e., BOT) it is evident that overall combustion behaviour is mostly additive with respect to total burn out time for the sawdust-char blends. For blends of corn cob char, similar synergistic effects were observed in initial and major combustion zone as it is evident from resulted Ti and DTG peak temperatures. Only difference is that for these blends burn out time (indicated as BOT) is more than the expected average figures.

This indicate that combustion parameters is boosted in initial and major combustion zone, but terminal firing consumes much larger time making total burn out time even more than expected weighted average time frame (anti synergistic effect).

Activation energy (E_{act}) of the blend samples (Table 2) was found in the range of 63.1-98.2 kJ/mol and pre-exponential factors (log A) were in between 2.4-4.9S^{-1}. It was observed that the activation energies of the entire blend samples decreases with increasing percentage of corn cob and saw dust char. It was also observed that the values are lower than those expected from weighted average values, which is the indication of the positive interaction of the biomass chars with coal in the blends which brings out synergistic effect during combustion. So, there is a clear indication of positive influence of blending of biomass chars with coal.

Theoretical rate of mass loss of the blend at any instant of time or temperature may be represented as

$$(dm/dt)_{blend} = x_1*(dm/dt)_{coal} + x_2*(dm/dt)_{biomass}$$

where $(dm/dt)_{coal}$, $(dm/dt)_{biomass}$ are the normalized rates of mass loss, as found from the individual experiments, and x_1, x_2 are the mass fraction of coal and biomass chars in the blend respectively. Comparison between theoretical and experimental rate curves for the representative blends of coal-biomass chars are shown in Fig. 2 and 3. For blend containing 10% biomass chars experimentally observed rate curves follows the theoretically expected curve. Deviation of experimentally obtained rate curves from theoretical curves was observed for all other blends, where experimental curves found to be shifted towards left of corresponding theoretical rate curves. Deviation between the two curves is due to mutual interaction between coal constituents and constituents of biomass chars. Double peaks in Fig.3 depicts the prediction on combustion behaviour of the blends which suggests that burning should occur in a segregated way. That means burning behaviour of the components should not be synchronized if addtiivity criteria is followed. In practice experimental curves show single peak indicating synchronized burning of the blend constituents. As a whole co-combustion rate characteristics indicate significant improvement of combustion reactivity over those estimated from characteristics of individual components.

4. CONCLUSIONS

From the TGA results it may be concluded that co-combustion of biomass chars with coal is a potential option to improve combustion performance as compared to either of the components. Synergistic effects are quite expected in such cases as it is evident from the characteristics of blends containing up to 50% biomass char. More amounts of biomass char in the blend should only be attempted if it does not bring out additional handling/ processing problem and is found safe in respect of possible slagging/fouling. Results obtained through TGA studies although cannot fully predict the burning characteristics in utility operation, those may provide valuable inputs for design and operation related issues as well as for selection of appropriate blend-combination. Such studies also give adequate support for judicious selection of blend-proportion for specific blend combination. As such the results are useful for promoting the use of biomass char as a carbon neutral co-fuel for power generation.

Acknowledgement: The authors are thankful to the Director of CSIR-Central Institute of Mining and Fuel Research for giving permission to publish the paper. The work presented in this paper is the part of Ph. D work of Sri S. G. Sahu, carried out under the guidance of Dr. Pinaki Sarkar. The authors also express their gratitude to the authority of the Jadavpur University, Kolkata, India for providing necessary support and approval to undertake the Ph. D programme.

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ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 126-130*

Table 1: Chemical composition of coal and biomass (air dried basis)

Sample	**M**	**A**	**VM**	**FC**	**C**	**H**	**N**	**S**	**GCV (kcal/kg)**
Coal	10.1	49.5	19.4	21.0	29.6	2.4	0.71	0.43	2730
SD char	4.7	8.6	29.4	57.3	62.4	2.3	0.12	0.05	4951
CC char	7.9	6.8	24.4	60.9	63.2	3.8	0.41	0.15	5665

Table 2: Combustion parameters of coal, saw dust char, corn cob char and their blends

Sample	**Ti (^oC)**	**DSC (^oC)**	**DTG (^oC)**	**BOT (^oC)**	**log A (S^{-1})**	**Eact (kJ/mol)**	**Correlation coefficient**
Coal	359.6	427.4	428.4	493.4	5.65	108.72	0.9997
SD Char	285.5	419.6	414.5	482.0	3.13	74.00	0.9974
CC Char	285.1	380.9	364.3	427.2	6.37	108.86	0.9985
BSD1	334.4	423.4	416.3	492.6	4.89	98.15	0.9997
BSD2	314.9	410.2	406.8	488.9	4.57	92.50	0.9992
BSD3	316.3	421.4	415.5	502.8	3.90	85.08	0.9997
BSD4	305.0	407.2	403.3	492.1	3.91	83.82	0.9993
BSD5	291.3	389.2	382.9	481.0	3.94	82.41	0.9984
BC1	332.9	420.6	415.6	502.0	4.10	88.13	0.9998
BC2	326.3	412.5	407.5	493.3	4.14	87.49	0.9996
BC3	311.4	395.2	388.8	486.6	3.94	83.25	0.9995
BC4	294.0	374.8	369.1	482.1	3.96	81.64	0.9984
BC5	291.0	385.2	361.6	481.2	2.41	63.13	0.9954

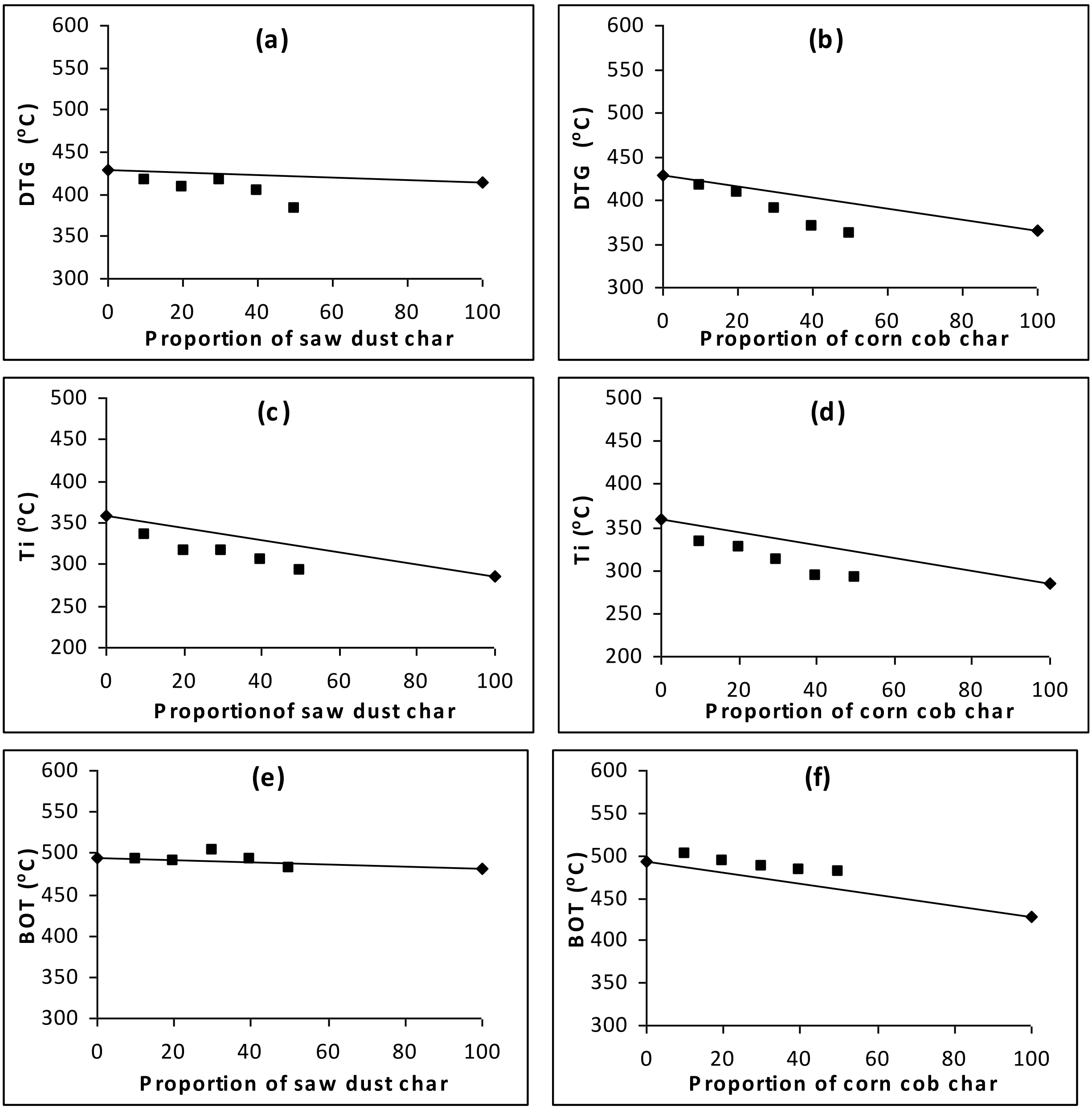

Fig.1 (a-f). Variation of TGA parameters with proportion of biomass chars

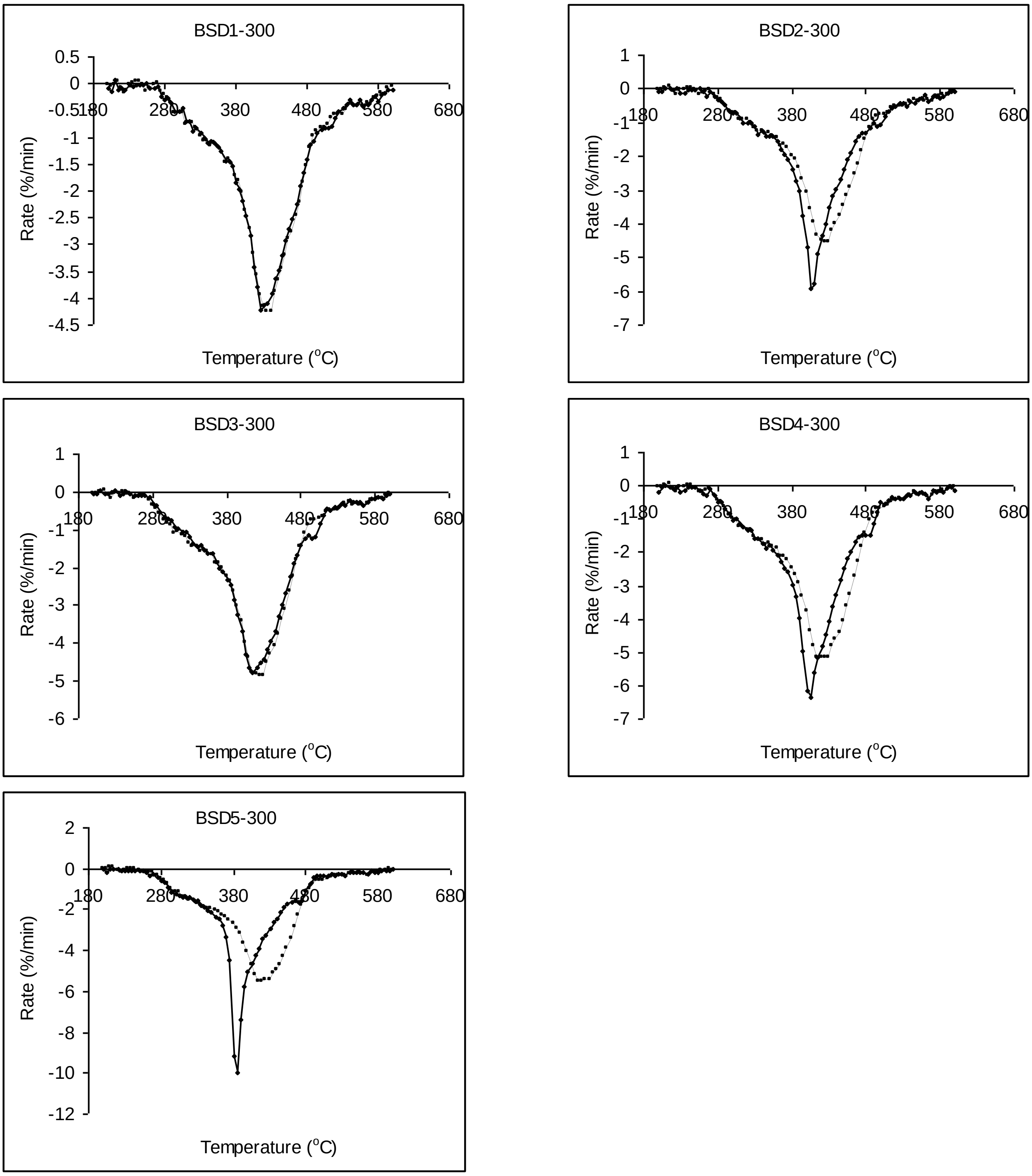

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Fig.2. Comparison between theoretical and experimental rate of coal-saw dust char blends

ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 126-130*

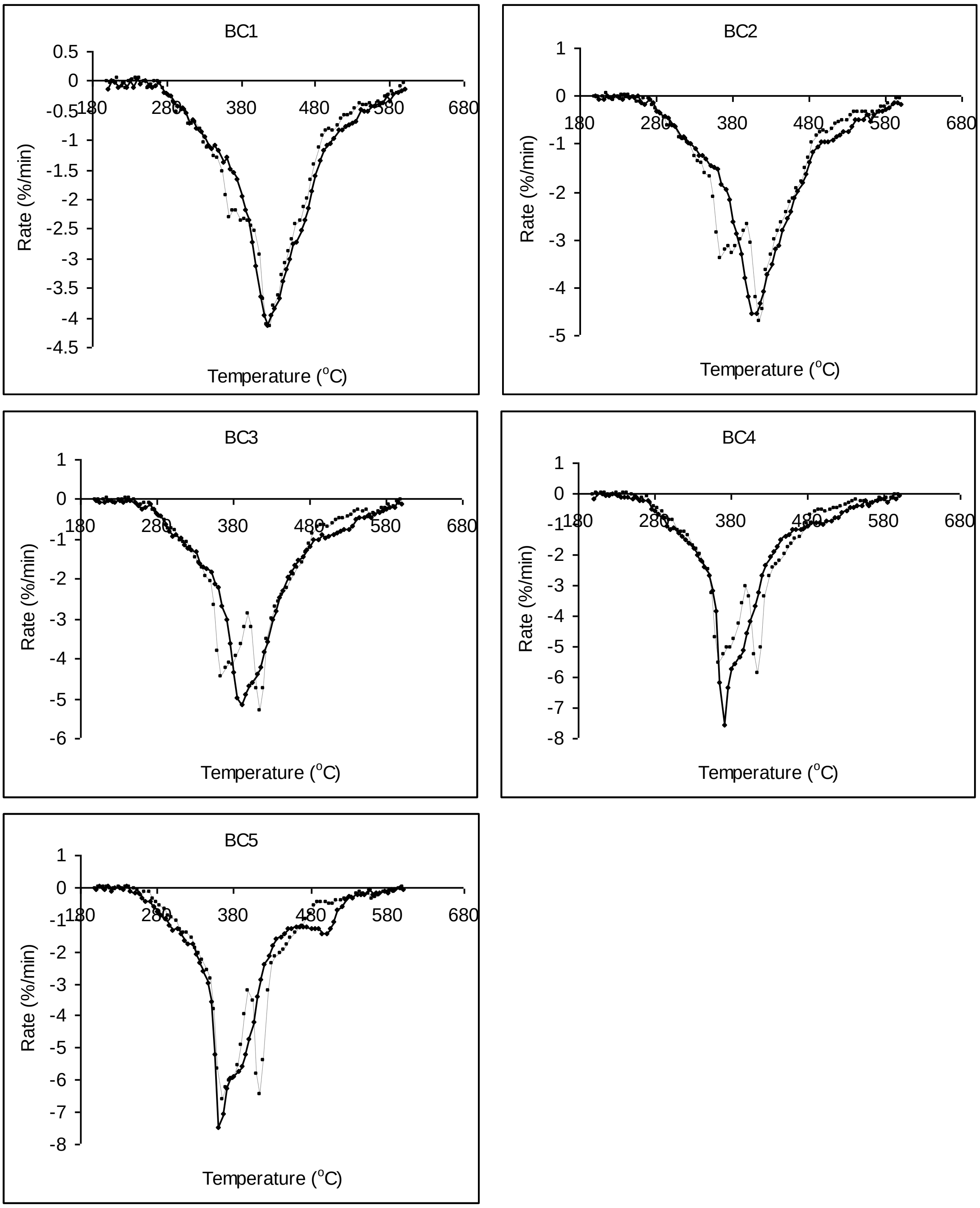

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Fig.3. Comparison between theoretical and experimental rate of coal-corn cob char blends

ISSN 2250-2459, *Volume 3, Special Issue 3: ICERTSD 2013, Feb 2013, pages 126-130*

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