Activation Energy Analysis of Thermal Degradation of Bamboo Fiber by Coats & Redfern Method

N. Shukla[1*], G.L. Devnani[2]
[1*]*Chemical Engineering Department, H.B.T.U. Kanpur, 208002, U.P, India*
[2]*Chemical Engineering Department, H.B.T.U. Kanpur, 208002, U.P, India*

Abstract **Bamboo fiber is a dominant fiber in the category of sustainable natural fibers. It is easily available across the globe. Substantial amount of work has been done on the characterization of this natural fiber and their reinforced polymer composites. Activation energy of thermal degradation of this novel fiber is another important aspect which need to be addressed to have a better idea of thermal degradation. This article describes about the activation energy of Bamboo fiber by Thermo-Gravimetric Analysis at single heating rate of 10ºC/minute.**

Keywords: Bamboo fiber, Composites, Activation Energy, Thermal Degradation

I. INTRODUCTION

Scientific Community all across the globe is looking for sustainable, environment friendly and cost effective substitutes of existing technologies and materials. Natural fibers as a replacement of synthetic fiber is one important area which is gaining importance day by day [1]. Bamboos are the perennial plants, belonging to the subfamily of Bambusoideae & grass family Phocaea with over 90 Genera & 1200 species. Bamboo fibers are cost-effective, biodegradable & light in weight. The bamboo Fibers along with substantial mechanical properties have the potential to fix environmental carbon dioxide [2]. Due to its feasibility, robust strength & high growth rates, studies found that Bamboo possess the latent to be used as the fiber for reinforcement in the composite materials. Cellulosic content in bamboo fiber is lesser than banana fiber. Mechanical properties of bamboo fiber also different. It shows more tensile strength, when it is mixed with polymer matrix material it form a composites with good mechanical properties.

Thermogravimetric analysis (TGA) is an essential device to examine thermal stability and kinetic parameters [3]. With the help of TGA information reinforced material can be implemented in many application. Bamboo Fibers Reinforced Composites have a diverse numbers of applications which ranges from automotive industry to the housing sectors [4]. Thermogravimetric analysis is used to see degradation of weight with respect to temperature. It is concluded from various results that fiber degradation occur after approx. 250˚C [5]. Thermal degradation of Kans grass is observed for untreated, 3% alkali treated, 5 % alkali treated & degradation start at 413, 418, 438˚C respectively [1].

2. EXPERIMENTAL

2.1 Material & Methods

The Bamboo fiber purchased from vruksha composites and service Chennai [6]. Fibers were dried in ambient condition & cut to 60-70 mm before use it. All the chemicals used here were purchased from local market. To find the activation energy coats & Redfern method is used at single heating rate [7].

3. THERMAL KINETICS BY COATS & REDFERN METHOD FOR FINDING ACTIVATION ENERGY

Different methods can be used for finding activation energy[8]. There are three types of method can be used for finding activation energy like Friedman, KAS, FWO. These all three methods are useful in case of different heating rate but if u want to find activation energy at single heating rate then coats & Redfern method is suitable [9].

Under isothermal condition, the reaction rate is defined as

$$d\alpha/dt = k\,f(\alpha) \qquad (1)$$

Where, k is reaction rate, t is reaction time, n is reaction order, a is defined in terms of change in mass of samples

$\alpha = (x_0 - x)/(x_0 - x_f)$

(2)

The reaction rate of decomposition is a function of temperature, usually given by Arrhenius equation:

K= A exp (-E/RT)

(3)

Where A is pre-exponential factor (s-1), E is activation energy (J/mol), R is universal gas constant & T is temperature.

Substituting the reaction rate into equation (1)

$d\alpha/dt = A \exp(-E/RT) f(\alpha)$

(4)

For constant heating rate, β (K/s)

$\beta = dT/dt$ (5)

Inserting equation (5) into equation (4)

$d\alpha/dt = \beta\ (d\alpha/dT) = A \exp(-E/RT) f(\alpha)$ (6)

Since numbers of simultaneous reactions were involved in the biomass decomposition process, in order to solve eqn. (6) for the activation energy (E) and the frequency factor (log A), two methods were adopted in this study, one is a model-free method and the other one is a model-fitting method [10].

3.1 Model-fitting method: The integral method of Coats– Redfern derived from the Arrhenius equation has been widely applied for kinetics analysis of solid decomposition [11]. Separating variables in eqn. (6) gives:

$d\alpha/ f(\alpha) = d\alpha/ (1-\alpha)^n = (A/ \beta)\ X \exp(-E/RT)\ dT$

(7)

Integrating between the limits: $\alpha = 0$ at $T = T_0$ and $\alpha = \alpha$ at $T = T_\alpha$

$$\int_0^{\alpha} \left(\frac{1}{(1-\alpha)^n}\right) d\alpha = \int_{T_0}^{T_\alpha} \left(\frac{A}{\beta}\right) X \exp(-E/RT)\ dT \quad (8)$$

Integrating $(1-\alpha)^n$ and

$\exp\left(-\frac{E}{RT}\right)$ $in\ eqn, the\ following\ exression\ can\ be$ obtained

$$\frac{1-(1-\alpha)^{1-n}}{1-n} = \frac{ART^2}{\beta E}\left(1-\frac{2RT}{E}\right)\ X \exp\left(-\frac{E}{RT}\right) \quad (9)$$

Transforming this equation into logarithmic expression

$$\ln\left(\frac{1}{T^2}\frac{1-(1-\alpha)^{1-n}}{1-n}\right) = \ln\left(\frac{AR}{\beta E}\left(1-\frac{2RT}{E}\right)\right) - \frac{E}{RT} \quad (10)$$

Assuming $\left(1-\frac{2RT}{E}\right) \approx 1$ equn 10 becomes

$$\ln\left(\frac{1}{T^2}\frac{1-(1-\alpha)^{1-n}}{1-n}\right) = \ln\left(\frac{AR}{\beta E}\right) - \frac{E}{RT} \quad n \neq 1 \quad (11)$$

$$\ln\left(\frac{-\ln(1-\alpha)}{T^2}\right) = \ln\left(\frac{AR}{\beta E}\right) - \frac{E}{RT} \quad n=1 \quad (12)$$

Where:

*α is decomposed fraction of fiber sample time t, n is decomposition order,

*a is heating rate of sample in ºC/min, T is temperature in K,

*A is frequency factor in s-1,

*R is universal gas constant 8.314 J/Kmol and E is the activation energy in kJ/mol.

3.2 Kinetic Analysis

To calculate the activation energy with the different parameter, the value of n i.e. at n= 0, 0.5, 1.5 & 2 is put in equation (11) and n = 1 in equation (12) and simultaneously obtained the plots. Fig.1 corresponds for single step at n=1.5. In this step the best fit curve is plotted & calculate the activation energy [12]. Activation Energy (E) is calculated by slope of (–E/2.303R) [14]. The best fit curve is obtained at order n = 1.5 its corresponding straight line equation obtained and corresponding values of kinetic parameters are listed in table 1 [13].

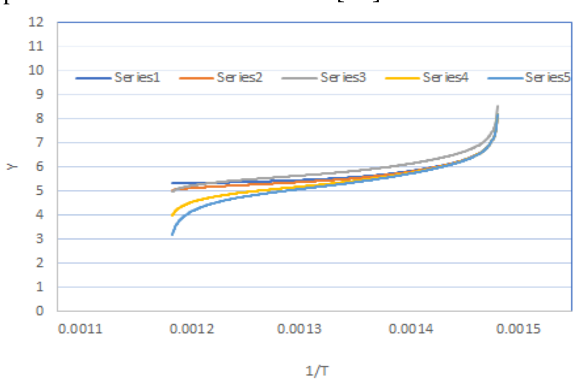

Fig. 1 indicates plot for bamboo fiber by Coats & Redfern Method. In the graph all series shows value of n, series 1, series 2, series3, series 4 & 5 indicates value of n=0, 0.5, 1, 1.5, 2. Table 1 corresponds to kinetic data of untreated bamboo fiber. Different value is obtained by Coats & Redfern method [15].

Table 1. Kinetic data of untreated bamboo fiber

Temperature Range (°C)	Parameters	Value
	n = 1.5	
650 – 850 K	E (kJ/mol)	92

CONCLUSION

Bamboo fiber is used as natural fiber & reinforcement material for preparation of composites. Different method can be used to find activation energy at different heating rate but in this work Coats & red fern method is used to find activation energy at single heating rate. Activation energy of fiber is calculated with the help of TGA curves. One steps is followed to find activation energy at n = 1.5 & activation energy is 92 kJ/mol.

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