

# DISTRIBUTED ACTIVATION ENERGY MODELLING FOR PYROLYSIS OF FOREST WASTE USING GAUSSIAN DISTRIBUTION

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The paper focuses on the influences of some factors significant to pyrolysis of forestry biomass on the asymptotic solution of the non-isothermal n<sup>th</sup>-order distribution energy model (DAEM) using Gaussian distribution. Investigated parameters are the integral upper limit, the frequency factor, and the heating rate parameters of the Gaussian distribution. The influence of these factors has been used for evaluating the kinetic parameters of the non-isothermal n<sup>th</sup>-order Gaussian distribution from thermogravimetric analysis of forest waste.

Key words: distributed activation energy model (DAEM), non-isothermal kinetics, asymptotic solution, Gaussian distribution.

## INTRODUCTION

Chir pine trees are abundant in altitudes ranging from 1000 m to 2000 m in the Himalayan region of India. Needles that fall from pine trees have traditionally been used by indigenous communities for carpeting cattle sheds as well as cooking purposes during monsoon, and as fertiliser (Dhaundiyal and Tewari, 2015). However, being highly combustible due to the high percentage of lignin, pine needles intensify forest fires and create problem to the environment (Ghosh and Ghosh, 2011; Dhaundiyal and Gupta, 2014). The forest thinning of chir pine (pinus roxburghii) trees is responsible for a large amount of forest waste in the form of pine needle litter, which still contains significant energy potential. Non-utilisation of pine needles and consignment of them to waste on forest floor is unethical and uneconomical. Moreover, a higher level of utilisation of residual biomass energy potential could be used in energy production.

There are various models which have been used to demonstrate biomass pyrolysis mathematically. Mainly, these models can be classified as: the single-reaction and the multi-reaction models (Conesa *et al.*, 1995; Conesa *et al.*, 2001; Capart *et al.*, 2004; Pysiak and Badwi, 2004; Criado *et al.*, 2005; Mysyk *et al.*, 2005). The most accurate and well defined approach for the modelling of biomass pyrolysis is to adopt the distributed activation energy model (DAEM) (Burnham *et al.*, 1995; Burnham and Braun, 1999; Ferdous *et al.*, 2002; Galgano and Blasi, 2003). The distributed activation energy model also applies to the pyrolysis of

numerical complication. This paper used the asymptotic method to make an accurate approximation for the mathematical simulation of biomass pyrolysis as well as examined the effects of various kinetic parameters on the numerical results of the non-isothermal,  $n^{th}$ -order DAEM, using the Gaussian distribution.

## MATERIALS AND METHODS

ture (Teng and Hsieh, 1999)

The non-isothermal  $n^{th}$  DAEM pyrolysis of forest waste using the Gaussian distribution and its asymptotic solu-

other materials, including fossil fuel, residual oils, resin chars (Zhu et al., 2009), medical waste (Koreňová et al.,

2006), waste car tires (Folgueras et al., 2003), sewage

sludge (Lakshmanan et al., 1991) and kerogen (Brown,

1988). DAEM has proven to be very successful in describ-

ing pyrolysis of various types of biomass under varying

temperature ranges. The asymptotic solutions of the kinetic

model equation are used to evaluate the kinetic parameters.

In order to obtain a good approximation, the parameters af-

fecting the numerical solutions of the model equation must

be known. Influence of various parameters affecting the nu-

merical solution of single reaction models is stated in litera-

The paper focussed mainly on parametric values relevant to

forest waste. The numerical solution of the DAEM requires

the iterative evaluation of a double integral, which involves

rapidly varying functions, and hence, resulting significant

tions. The concept of DAEM was proposed by Vand (Vand, 1943) and it was adopted in coal the devolatilisation problem by Pitt (Pitt, 1962). Later, the model was used by Hanbaba and his co-worker (Hanbaba *et al.*, 1968), and Anthony and Howard (1976) in their work. The model postulates that the decomposition mechanism takes a large number of independent, parallel, and the first order chemical reactions with different activation energies exhibiting variation in the bond strength of constituent species of biomass. Here in this paper, we discussed first order as well as  $n^{th}$ -order DAEM and the derivation can be found in literature (Antal *et al.*, 2006). The non-isothermal  $n^{th}$  order DAEM is given below:

$$1-X = \begin{cases} \int_{0}^{\infty} \exp\left[-\int_{T_{0}}^{T} \frac{A}{\Theta} \exp\left(\frac{-E}{RT}\right) dT\right] f(E) dE \\ first \ order \\ \int_{0}^{\infty} \left[1-(1-n)\int_{T_{0}}^{T} \frac{A}{\Theta} \exp\left(\frac{-E}{RT}\right) dT\right]^{\frac{1}{(1-n)}} f(E) dE \\ n^{th} - order \ (n \neq 1) \end{cases}$$
(1)

where *E* is the activation energy,  $\Theta$  is the heating rate, *A* is the frequency factor, *R* is the ideal gas constant, *n* is the reaction order, *T* is absolute temperature, *T<sub>o</sub>* is the initial reaction temperature, *X* is the conversion rate and *f*(*E*) is the initial distribution function of activation energies.

The activation energy distribution can be considered by using the Gauss, the Gamma or the Weibull distribution functions. Usually, the Gaussian distribution is used to describe activation energy distribution since the integral curve of biomass pyrolysis decomposition is similar to the Gauss function.

The integrand in equation (1) consists of two parts. The first double exponential (DExp) term depends on time through which the temperature range varies in non-isothermal pyrolysis. The second part is independent of time and depends solely on the distribution of activation energy of constituents. The behaviour of the temperature dependent part DExp is considered first and thereafter a useful approximation is derived, which are relevant for biomass pyrolysis. The non-isothermal temperature regime is investigated together with initial distribution of volatile content of biomass.

**Double Exponential Integrand simplification for DAEM**. Approximation to the double exponential is considered. The approach applied here is similar to that of Niksa and Lau (Niksau and Lau, 1993), but it is different in the sense that we used a more systematic method and a more accurate approximation.

$$DExp = \exp\left(-\int_{0}^{t} Ae^{-\frac{E}{RT(l)}}dt\right)$$
(2)

where T(l) is specified temperature and E can take any positive value.

In order to apply the systematic simplifications of this integrand it is necessary to assume some typical range of the parameters and functions on which it depends. The frequency factors are typically in the range of  $10^{10} \le A \le 10^{13} \text{s}^{-1}$ , whereas the activation energies fall into the region of 100- 300 kJ mol<sup>-1</sup>. The temperature history depends on the particular experiments, but 100 to 600 °C is mainly used in pyrolysis. However, we can also apply the same approach in the combustion problem where the temperature range can be significantly larger than any other applications. It is easier to extrapolate in the higher temperature range than that of the lower temperature regimes. In order to describe the stepwise simplification of the Gaussian distribution, the case of ramping temperature is used. Taking a typical value,  $\frac{E}{RT} \sim 10$  whereas  $tA \sim 10^{10}$ . The large size of both of these parameters makes the function very rapidly vary with E.

If the temperature variation is considered to ramp linearly with time, t, DExp becomes

$$T = \Theta t \tag{4}$$

$$DExp = \exp\left(-\int_{0}^{t} Ae^{-\frac{E}{R_{\theta l}}} dl\right)$$
(5)

In equation (5), the integral in the exponent can be approximated by using the conventional Laplace approach, where  $E_{R\Theta t}$  is assumed to be large and hence the dominant contribution from the integral is when 1 is near the stationary point, t (and corresponding temperature is near its maximum). Hence, this provides a well known asymptotic approximation to the function:

$$DExp = \exp\left(-\int_{0}^{t} Ae^{-\frac{E}{Rol}} dl\right) \sim$$
$$\sim \exp\left(\frac{-ARet^{2}}{E}e^{-\frac{E}{Rol}}\right) as \frac{E}{Rot} \to \infty$$
(6)

Equation (6) can be rewritten as:

$$DExp = \exp\left(-\exp\left(\frac{E_s - E}{E_w}\right)\right)$$
(7)

As E increases over a range of size  $E_w$  around  $E_s$ , the function varies rapidly from zero to one and this can be approximated as below.

Defining g(E) as:

$$g(E) = \left(\frac{E_s - E}{E_w}\right)$$

Then equation (7) can be rewritten as

$$DExp = \exp(-\exp(g(E)))$$

where 
$$g(E) = \frac{-E}{R\Theta t} + \ln\left(\frac{AR\Theta t^2}{E}\right)$$
 (8)

As behaviour of function near  $E_s$  is of interest, expand g(E) with the help of Taylor series

$$g(E) \sim g(E_s) + (E - E_s)g'(E) + \dots$$
 (9)

Using equation (8) and the predefined function g(E), the values of  $E_s$ ,  $E_w$  are chosen in such a manner such that

$$g(E_s) = 0 \text{ and } g'(E_s) = -\frac{1}{E_w}$$

After solving equations (8) and (9), we obtain

$$E_s = R \Theta t W(At) \tag{10}$$

$$E_w = \frac{R \Theta t E_s}{R \Theta t + E_s} \tag{11}$$

where, W(x) is a Lambert W function, which is one of real roots of the equation

 $We^x = x$ 

It is important to know the approximation of W(x) for long and short duration of times (Armstrong and Kulesza, 1981), hence

$$W \sim \ln\left(\frac{x}{\ln\left(\frac{x}{\ln(x)}\right)}\right)$$
 (for  $1 \ll x$ )

and 
$$W \sim x - x^2$$
 (for  $x \ll 1$ )

DExp varies like a smooth step function, rising rapidly (for larger values of product of frequency factor and time, (A.t)) from zero to one in the range of activation energies of width  $E_w$  around the value of  $E = E_s$ , where both  $E_s$  and  $E_w$  vary with time. In the total integrand of equation (1), DExp is multiplied by the initial distribution function f(E). The initial distribution is mainly centred around mean activation energy  $E_0$  and has a width designated by standard deviation,  $\sigma$ , both of which are constant. There are two different limits to evaluate the Gaussian distribution: wide initial distribution and narrow initial distribution. The wide initial distribution has wide initial distribution compared with the width of DExp; whereas the narrow distribution is relatively narrow with respect to width of DExp. The shape of the total integrand depends on which limit is applied. When the initial distribution is relatively wide compared to  $E_w$ , the total integrand behaves similarly to the initial distribution f(E). As time proceeds, the initial distribution is progressively chopped off from the left by the step-like function, DExp. The location of the maximum of the total integrand can move significantly, and the shape becomes quite skewed. When the initial distribution is relatively narrow, the total integrand remains similar in shape to the initial distribution with amplitude that is subsequently reduced by Dexp as time proceeds. Symmetrically, the total integrand in the narrow distribution is more symmetrical than that of the wide distribution limit. However, the location of the maximum changes as time varies. Here we discuss only the wide distribution case. In order to describe the approach, the initial distribution f(E) is assumed to be the Gaussian, centred at the mean activation energy,  $E_0$  with standard deviation,  $\sigma$ . Approximation is sought to the integral

$$1 - X = \frac{1}{\sigma\sqrt{2\pi}} \int_{0}^{\infty} \exp(h(E)) dE$$
(12)

where,

$$h(E) = -\exp\left(\frac{E_s - E}{E_w}\right) - \left(\frac{(E - E_0)^2}{2\sigma^2}\right)$$

 $E_s$  and  $E_w$  are functions of time as stated in equation (10) and Equation (11), respectively.

The rescaling factor 'y' is introduced to rescale energy as:

$$y = \frac{E}{E_0}$$

So that problem becomes

$$1-X = \frac{1}{\sigma\sqrt{2\pi}} \int_{0}^{\infty} \exp\left[-\exp\left(\frac{y_s - y}{y_w}\right) - \beta(y - 1)^2\right] dy$$
(13)  
$$h(y) = -\exp\left(\frac{y_s - y}{y_w}\right) - \beta(y - 1)^2$$

where the constant parameter  $\beta = \frac{E_0^2}{2\sigma^2}$ . Note that in practice, the value of  $\beta \gg 1$ .  $\Theta \theta$ 

For 
$$T = \Theta t$$
,  $y_s = \frac{R \Theta \tau W(\tau)}{AE_0}$  and  $y_w = \frac{y_s}{1 + W(\tau)}$ 

where, W ( $\tau$ ) is the Lambert W function and time has been rescaled as  $\tau = At$ .

The wide distribution. First order reaction. In order to apply this, the limit  $y_w \sqrt{\beta} \ll 1$  is considered. As discussed previously, DExp leaps from zero to one near  $y = y_w$ , in a manner that has been approximated in literature (Vand, 1943; Howard, 1981; Suuberg, 1983; Niksa and Lau, 1993) by the step-function.

$$U(y - y_s) = \begin{cases} 0, y < y_s \\ 1, y \ge y_s \end{cases}$$

Equation (13) can be rewritten as:

$$1-X = \sqrt{\frac{\beta}{\pi}} \int_{0}^{\infty} \left[ \exp\left(-\exp\left(\frac{y_s - y}{y_w}\right)\right) - U(y - y_s) \right] e^{(-\beta(y-1)^2)} dy + \sqrt{\frac{\beta}{\pi}} \int_{0}^{\infty} e^{(-\beta(y-1)^2)} dy$$
(14)

As it is clearly seen, the second integral is a complementary error function, and therefore it can be easily computed. The integrand in the first integral is multiplied by a function that is negligibly small everywhere except in a neighbourhood of size  $y_{W}$  around the point  $y = y_s$ . Therefore, this can be approximated by expanding the initial distribution term as a Taylor series about  $y = y_s$  giving

L.H.S = 
$$\sqrt{\frac{\beta}{\pi}} \int_{0}^{\infty} \left[ \exp\left(-\exp\left(\frac{y_s - y}{y_w}\right)\right) - U(y - y_s) \right] e^{(-\beta(y-1)^2)} dy =$$
  
=  $\sqrt{\frac{\beta}{\pi}} \int_{0}^{\infty} \left[ \exp\left(-\exp\left(\frac{y_s - y}{y_w}\right)\right) - U(y - y_s) \right] \cdot$   
 $\cdot (1 + 2\beta(y_s - 1)(y - y_s) + \frac{2\beta(1 + 2\beta(y_s - 1))(y - y_s)^2}{2!} +$   
 $+ \dots) e^{(-\beta(y_s - 1)^2)} dy$ 

Each of the integral terms, arising from a term in the Taylor series, can be separately integrated to yield

$$1-X = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\beta} (y_s - 1) \right) + \sqrt{\frac{\beta}{\pi}} y_w e^{(-\beta(y_s - 1)^2)} \left[ \alpha_0 - \frac{-2\beta y_w (y_s - 1)\alpha_1 + \beta y_w^2 \{2\beta(y_s - 1)^2 - 1\}\alpha_2 + \frac{2}{3} y_w^3 \beta^2 \{2(y_s - 1) + 2\beta(y_s - 1)^3 + 1\}\alpha_3 \right]$$

where the remaining integrals to be evaluated are represented by

$$\alpha_{i} = \int_{-\infty}^{\infty} x^{i} \left( e^{-e^{-x}} - U(x) \right) dx, i = 0, 1, 2, 3, \dots$$

The values of  $\alpha_i$  need to be calculated once, as they are independent of any other parameters.

$$\alpha_0 \approx -0.5772, \alpha_1 \approx -0.98906, \alpha_2 \approx -1.81496, 
\alpha_3 \approx -5.89037, \alpha_4 \approx -7.3969$$

Similarly for  $n^{th}$  order reaction, we can derive the expression by using equation (13)

$$1-X = \sqrt{\frac{\beta}{\pi}} \int_{0}^{\infty} \exp(-\beta(y-1)^{2}) - \sqrt{\frac{\beta}{\pi}} \left[ \int_{0}^{\infty} \exp\left(\left(\frac{y_{s}-y}{y_{w}}\right) - \beta(y-1)^{2}\right) + \frac{n}{2} \left(\int_{0}^{\infty} \exp\left(2\left(\frac{y_{s}-y}{y_{w}}\right) - \beta(y-1)^{2}\right)\right) \right]$$
(15)  
$$1-X = \sqrt{\frac{\beta}{\pi}} \int_{0}^{\infty} \exp(-\beta(y-1)^{2}) - \frac{1}{2} \operatorname{erfc}\left(\sqrt{\beta}(y_{s}-1) + y_{w} e^{(-\beta(y_{s}-1)^{2})} \sqrt{\frac{\beta}{\pi}} \left[ (B_{0} - 2y_{w}\beta(y_{s}-1)B_{1} + \beta y_{w}^{2} \{2\beta(y_{s}-1)^{2} - 1\}B_{2} - \frac{2}{3}y_{w}^{3}\beta^{2}(y_{s}-1)B_{3} \{(2\beta(y_{s}-1)^{2} - (-3))\} + \frac{1}{6}B_{4}\beta^{2}y_{w}^{4} \{(4\beta^{2}(y_{s}-1)^{4} - 12\beta(y-1)^{2} + 3)\} \right] + \frac{1}{6}B_{4}\beta^{2}y_{w}^{4} \left\{(4\beta^{2}(y_{s}-1)^{4} - 12\beta(y-1)^{2} + 3)\} \right] + \frac{1}{6}B_{4}\beta^{2}y_{w}^{4} \left\{(1-\beta^{2}y_{w}) + \frac{1}{6}B_{4}\beta^{2}y_{w}^{4} \left\{(1-\beta^{2}y_{w}) + \frac{1}{6}B_{4}\beta^{2}y_{w}^{4} + \frac{1}{6}B_{4}\beta^{2}y$$

$$+ \frac{n}{2} \left[ \frac{1}{2} \operatorname{erfc}(\sqrt{\beta}(y_s - 1) - \frac{1}{2} y_w e^{(-\beta(y_s - 1)^2)} \sqrt{\frac{\beta}{\pi}} \left[ (B_0 - 2y_w \beta(y_s - 1)B_1 + \beta y_w^2 \{ 2\beta(y_s - 1)^2 - 1 \} B_2 - \frac{2}{3} y_w^3 \beta^2 (y_s - 1)B_3 \{ (2\beta(y_s - 1)^2 - 3) \} + \frac{1}{6} B_4 \beta^2 y_w^4 \{ (4\beta^2 (y_s - 1)^4 - 12\beta(y - 1)^2 + 3) \} \right]$$

$$B_0 \approx 1, B_1 \approx 1, B_2 \approx 2, B_3 \approx 6, B_4 \approx 24$$

The remaining integral terms to be expressed are as follows:

$$B_i = \int_{-\infty}^{\infty} x^i \Big( e^{-x} - U(x) \Big) dx$$

**Application**. For applications, a thermogravimetric experiment has been conducted for the non-isothermal pyrolysis of pine needles samples in the presence of the inert gas, nitrogen. It has been noted that the experimental results of this paper have implemented in the process of obtaining the  $n^{th}$ -order Gaussian DAEM prediction. Chemical composition of pine needles sample was evaluated using a CHN-O analyser, the results of which are shown in Table 1. Figure 1 shows the comparison of the  $n^{th}$ -order Gaussian DAEM simulated pyrolytic conversion with the experimental data. In addition, it was also shown that the  $n^{th}$ -order Gaussian DAEM fits the experimental data very well. The Matlab algorithm was used to simulate the thermo-gravimetric process.

### RESULTS

After implementing the asymptotic method and the energy rescaling (y) on equation (1), the outer 'dE' integration upper limit must be determined. For the parametric values rel-

Table 1

CHEMICAL COMPOSITION OF PINE NEEDLES

Biomass type	С	Н	Ν	0	V.M	H.H.V	S	Ash
Pine needle	53.64	5.36	0.62	33.92	68.4	20.8	0.20	2.1



*Fig. 1.* Comparison between experimental data and the  $n^{th}$ -order Gaussian DAEM prediction.



*Fig.* 2. The effect of upper limit ( $E_{\infty}$ ) of dE integral on the asymptotic results (A = 293 s<sup>-1</sup>,  $\Theta$  = 10°C/min, T<sub>0</sub> = 292.37); a, first order reaction, b,  $n^{th}$ -order, n = 2.1.

evant to biomass pyrolysis, the effects of upper limit  $(E_{\infty})$ of dE integral on the numerical results of the non-isothermal  $n^m$  order DAEM is shown in Figure 2. At the initial state of pyrolysis reaction, the remaining mass fraction (1-X) must be in the vicinity of one; whereas in Figure 2, it is seen that remaining mass fraction is less than one for  $E_{\infty} < 70$  kJ/mol. As  $E\infty$  approaches 80 kJ/ mol, the results are found to be more precise and closely approximate to each other. But as the value of  $E_{\infty}$  increases, a shifting of the inflexion point is seen; therefore at the higher values of  $E_{\infty}$ , the curves chop off from the bottom and shift to the right side at the low frequency factor. However, with increase in the value of the frequency factor, the upper limit of dE will also change. Therefore, 80 kJ/ mol can be used for the upper limit of the dE integral at the lower values of A. The main reason of shifting at the higher value is because, as the outer value increases, it moves away from the central value E<sub>s</sub>, and because the behaviour of the whole integrand is similar to the Gaussian distribution. As time proceeds, it moves away from the central value E<sub>s</sub>, and hence the inflexion does not occur (the whole integrand shifts away from zero to other values within the interpolating range).

The effect of the frequency factor (A) values on the numerical results is illustrated in Figure 3. According to these curves, increase in the frequency factor values causes (1-X) curves to shift to the left side. As the value of the frequency factor increases at the lower outer values of integral 'dE',



*Fig. 3.* The effect of the frequency factor (A) on the asymptotic results ( $E_{\infty} = 58 \text{ kJ/mol}, \theta = 10 \text{ °C/min}, T_0 = 292.37 \text{ K}$ ); a, first order reaction, b, *n*<sup>th</sup>-order, n = 1.5.

the central value has been shifted to the left side. In addition to shifting of the central value, the inflexion occurs at the lower temperature domain; whereas the lower values of frequency factor A shifts (1-X) curves to the right as time proceeds. The whole integrand curve behaves similar to DExp with increase in the value of A and hence the step size  $(y_w)$ approaches zero. So, (1-X) curves have the same behaviour as the complementary error (erfc) at the higher values of A.

The effect of heating rate on asymptotic solution is illustrated in Figure 4. The behaviour of the whole integrand with change in heating rate has shown that the remaining mass fraction curve is shifted towards the left with increase in temperature, and the inflexion point approaches the zero mass fraction. Thus, it is concluded that at the higher heating rate, the proylsis will be fast and the rate of conversion will also be increased. In addition, the remaining mass fraction curves become constant as time proceeds at the higher heating rates. With further increase in the heating rate, inflexion point will vanish and the remaining mass fraction curves behave linearly with temperature and become constant at the extremum of asymptotic solution.

The influence of the reaction order on the asymptotic solution is shown in Figure 5, where it is seen that increase in the reaction-order values (n) shifted the lower part of (1-X) curves down about the inflexion point; whereas the upper parts of curves lead toward the right direction. Using the effect of these parametric values,  $n^{th}$ -order Gaussian distribu-



*Fig.* 4. The effect of the heating rate ( $\Theta$ ) on the asymptotic results ( $E_{\infty} = 58$  kJ/mol, A = 293 s<sup>-1</sup>, T<sub>0</sub> = 292.37 K); a, first order reaction, b,  $n^{th}$ -order, n = 1.5.



*Fig.* 5. The effect of the reaction order (n) on the asymptotic results ( $E_{\infty}$  = 58 kJ/mol, A = 293 s<sup>-1</sup>, T<sub>0</sub> = 292.37 K, and  $\theta$  = 10 °C/min).

tion prediction was performed to compare it with thermoanalytical data, which is illustrated in Figure 5. The simulation of experimental data is very useful to provide accurate information of kinetics of biomass pyrolysis and with this information, kinetic parameters can be obtained.

#### CONCLUSIONS

The main purpose of this paper is to compare the mathematical behaviour with the thermal behaviour of forest waste, pine needles, using kinetics parameters that highly affect the kinetic mechanism of biomass pyrolysis. Using a mathematical model, we described the kinetic behaviour of biomass pyrolysis with respect to the selected parameters. The asymptotic solution of the non-isothermal  $n^{th}$ -order DAEM involved the Gaussian distribution for the main attribute of biomass pyrolysis kinetics; 80 kJ/ mol can be used for the upper limit of the outer dE integral. The variation in the frequency factor, the heating rate, and the reaction order merely shifted the inflexion point as well as affect the shape the mass fraction curves. The results are helpful for knowing the kinetic parameters of the non-isothermal  $n^{th}$ -order Gaussian DAEM from the thermo-analytical data of biomass pyrolysis. Mathematical simulation was conducted using the designed Matlab algorithm to optimise the thermogravimetric data to predict the behaviour of loose biomass with change in the temperature profile.

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MEŽA ATKRITUMU PIROLĪZES SADALĪTAS AKTIVĒŠANAS ENERĢIJAS MODELĒŠANA, IZMANTOJOT GAUSA SADALĪJUMU

Rakstā analizēta dažu mežu biomasas pirolīzes faktoru ietekme uz *n*-pakāpes sadalītas aktivēšanas enerģijas modeļa asimptotisko risinājumu, izmantojot Gausa sadalījumu.