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**Research Article**

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# Chemical reaction kinetics of coal combustion investigated by thermogravimentric analysis

**Guoping Jiang and Xiao Sanxia**

*School of Engineering, 2011 High Performance Concrete Coordination Center In Fujian Province，Fujian Jiangxia University, Fuzhou, Fujian, China*

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**ABSTRACT**

*A combustion model connected burnout with chemical dynamics parameters and quantitative study on it are rarely reported. Pulverized coal combustion reaction dynamics parameters are one of necessary important datum of thermal calculation on combustion equipment based on pulverized coal fuel and basic theory study on pulverized coal particle combustion characteristics .With the development of computer science , mathematical model of pulverized coal combustion is being applied to boiler design and operation little by little. This is required to calculate pulverized coal combustion process as accurately as possible, important initial data in the calculation is reaction dynamics parameters, it quantitatively describes reaction ability of coal and gives change rule of reaction ability of different coals with temperature .  According to need of HuNan Hua-Yin ZhuZhou power plant' 2nd alteration project , fifteen conventional coals that they provided and will burn in the power plant' W flame furnace are studied on conventional industrial analysis、 element analysis 、actual combustion characteristics and slagging characteristics. Adaptation reactions of coals are analyzed, coal ranges selected of better combustion effect in the flame furnace is given. ground is provided for determining burning coals.*

**Keywords**: coal combustion; chemical reaction kinetics; burnout ratio; thermogravimentric analysis

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## INTRODUCTION

Combustion of pulverized coal is complex and difficult to analyze and technique of which is immature so far. However, no matter from the aspects of environmental protection, or the boiler operation mode of the unit, research of combustion process needs to be strengthened. The characteristic of coal combustion state is so important that the wide attention of scholars are focus on this field. Hust, Sun and Lunden [1-2] proposed the carbon Burnout Model (CBK) to describe coke and reactive reduced with the increase of burnout ratio which found in the experiment. The results show that char oxidation is the slowest step for the process of coal combustion, the rate at which the heterogeneous reaction proceeds has an important effect on the degree of carbon burnout. Xu Xu[3] suggested that the cause of the activity decline maybe the microcrystalline of smoldering ember particles which produced under the condition of high temperature. Most research about abroad pulverized coal fired boiler was conducted in view of chamber of the furnace. Field [4], Smith[5] etc calculated burning temperature and burning rate in different char particle sampling points and found that with the state of burnout ratio increasing, a grey shells is formed at outside surface of coal tar grain, The diffusion resistance increased with the state of burnout ratio increasing . Calculation results of hole model presented by Chen Hong and Simons [6-8] confirm this. The research on combustion process till now almost belongs to the qualitative relationship, strictly the mathematical description of the relationship is far from established. The burnout ratio associated with chemical kinetics parameters for combustion mode are rare reported.

In this paper, A combustion model is provided , the model consider the apparent activation energy $E$ and the pre-exponential factor $A$ as function of burnout. Study on combustion characteristics of blended coal by thermogravimentric analysis is made . The change trends of the combustion rates for the several coals under different constant temperature levels were predicted.

**2 The establishment of the model**

Combustion of pulverized coal is a multiphase combustion, Badzioch present dynamic equation

$$\frac{da_v}{d\tau} = -k_0(a_{v_\infty} - a_v)\exp(-\frac{E}{RT}) \quad (1)$$

Where $k_0$ is Apparent frequency factor; $R$ is gas constant (8.31J/(mol.·K)) ; E is activation energy (J/mol) ; $T$ is particle temperature (K) ; $a_v$ is the quality of the precipitation volatilization in time $\tau$; At high temperature, because $E$ 、$k_0$ and $a_{v_\infty}$ are a function of temperature, so under the high temperature value is different from the value under the low or medium temperature. Eq.1 should be modified.

When reaction temperature is not high in the process of combustion, the chemical reaction speed is lower. The supply speed of oxygen is more larger than oxygen consumption speed in chemical reaction which lead to the combustion reaction area can be considered a dynamic area. The chemical kinetics factors can be controlled by reaction speed and approximately expressed in tired law of burning rate. So we can suppose the dynamics parameter is a function of the state of combustion. Eq.1 can be modified as Eq.2.

$$DTG(\alpha) = A(\alpha)\exp(-E(\alpha)/(RT)) \quad (2)$$

Where $DTG(\alpha)$ is burning rate (kg/kg /min), $A(\alpha)$ is pre-exponential factor(min－1), $E(\alpha)$ is activation energy (J/mol).

This model suggest that $E(\alpha)$ and $A(\alpha)$ are a function of chemical reaction. It has two meaning: (1) Coal combustion characteristics are different under different burnout ratio; (2) The same degree of combustion reaction has the same chemical kinetics constants. Using the thermobalance and the two heating rate, weightlessness rate curve can be determined from which $E(\alpha)$ and $A(\alpha)$ curves can be all obtained. $E(\alpha)$ and $A(\alpha)$ can be determined by Eq.3 and 4 from presented combustion model.

$$E(\alpha) = -\frac{R\ln\frac{DTG_1(\alpha)}{DTG_2(\alpha)}}{(\frac{1}{T_1(\alpha)} - \frac{1}{T_2(\alpha)})} \quad (3)$$

$$A(\alpha) = \frac{DTG_2(\alpha)}{\exp(-E(\alpha)/(RT_2(\alpha)))} \quad (4)$$

**2 The experiment**

The coal quality analysis of test sample is presented in table 1. There are four kinds of coals (a single coal, the three kinds of blended coals). TGA7 thermogravimetric analyzer of Perking - Elmer companies in the United States is used. The test conditions are(1)The heating rate: 10 ℃ / min, 15 ℃ / min, 20 ℃ / min. (2)Working temperature is from 25 ℃ to 850 ℃; (3)Work atmosphere is compressed air(4) Gas flow rate is 130 ml/min. (5) Quality of coal samples is （13±1）mg.(6) Pulverized coal fineness is 200 mesh sieve.

**Table1 Coal quality analysis of test sample**

| Type of coal | Industry analysis [wt.%] | | | | Elemental analysis [d.b.%] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $M_{ad}$ | $A_{ad}$ | $V_{ad}$ | $FC_{ad}$ | $C_{ad}$ | $H_{ad}$ | $O_{ad}$ | $N_{ad}$ | $S_{ad}$ |
| Ⅰ | 1.62 | 35.98 | 6.71 | 55.69 | 55.53 | 0.93 | 3.73 | 2.21 | 0.00 |
| Ⅱ | 1.41 | 35.13 | 7.64 | 55.82 | 56.31 | 1.42 | 3.21 | 2.50 | 0.02 |
| III | 1.56 | 35.81 | 10.17 | 52.46 | 55.18 | 1.66 | 3.41 | 2.00 | 0.38 |
| Ⅳ | 1.37 | 33.39 | 14.60 | 50.64 | 57.06 | 1.66 | 4.03 | 2.48 | 0.02 |

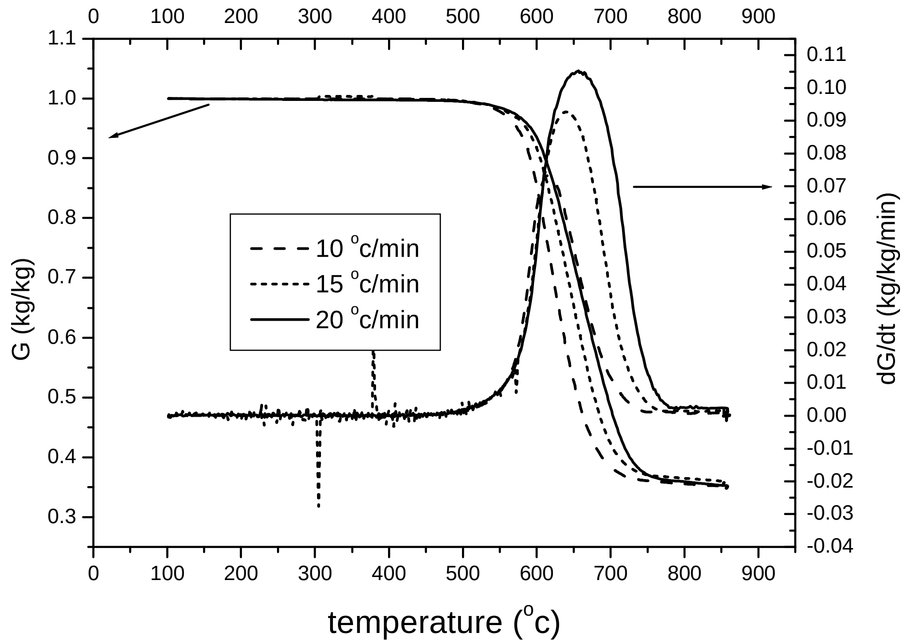


**Figure 1 TG, DTG curves of Ⅰ coal seam**

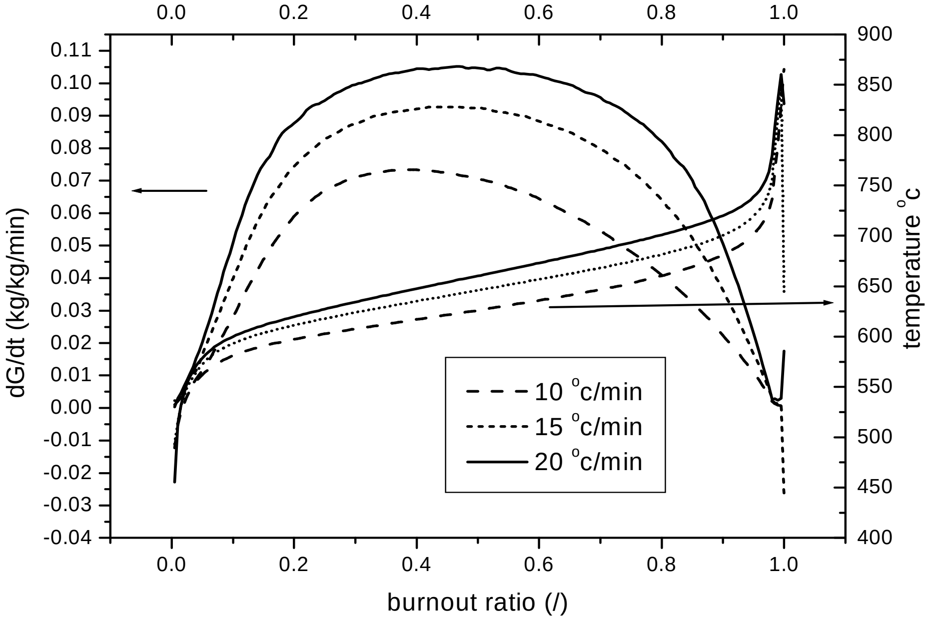


**Figure 2 Burning rate and combustion temperature changed burnout ratio with curves**

## RESULTS AND DISCUSSION

Select Ⅰ coal seam, with the heating rate of 10 ℃ / min, 15 ℃ / min, 20 ℃ / min, their TG, DTG curves can be obtained (Fig1). By test data and the burning rate curve, the burning rate curve are calculated and the results are presented in Fig 2. With the heating rate of 15 ℃ / min and 20 ℃ / min, $E(\alpha)$ and $A(\alpha)$ curves are obtained (Fig 3). The calculated and tested results are compared in Fig4. Dotted line represents the model computed result, solid lines represent the heat balance results. The calculated results coincide well with the test results.

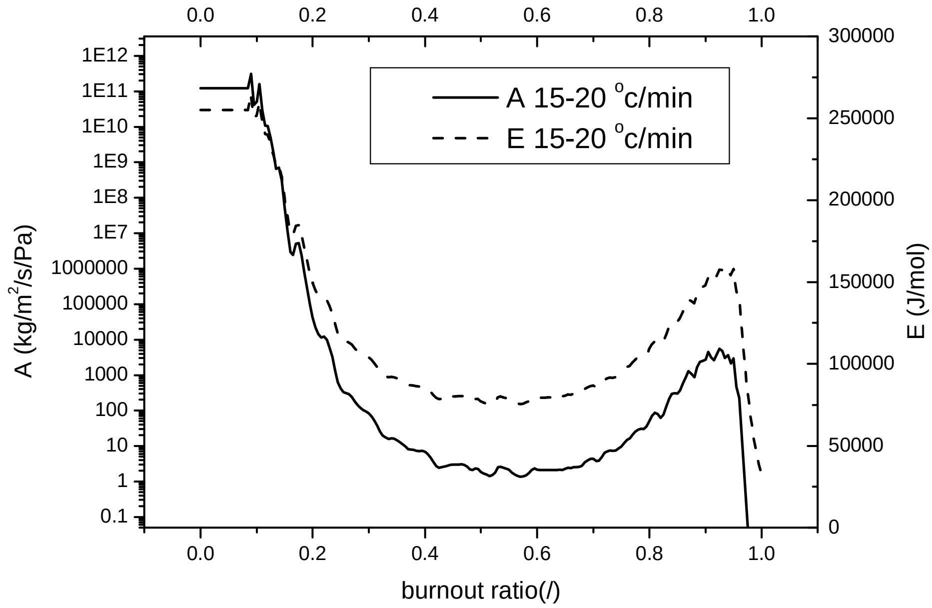


**Figure 3 $E(\alpha)$ and $A(\alpha)$ changed with burnout ratio curves**

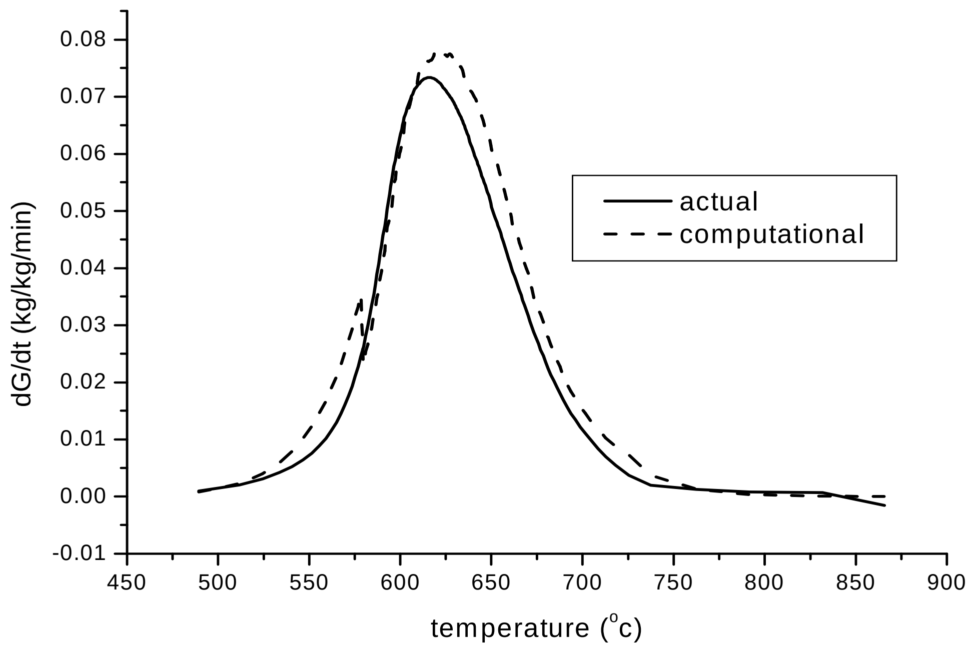


**Figure 4 The calculated and tested results compared**

With the model, combustion rate under different temperature can be obtained (Fig5, fig6).

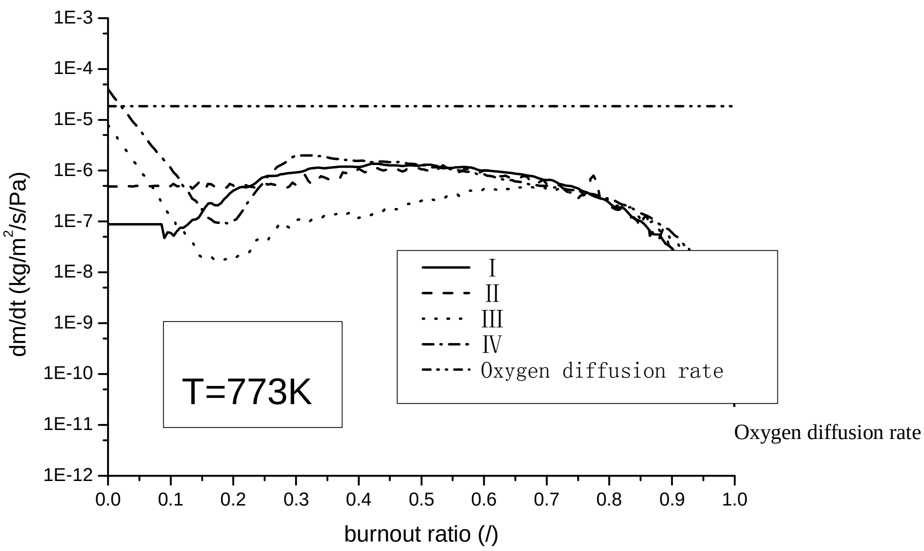


**Figure 5 The burnout ratio of the four coals predicted under the temperature 773K**

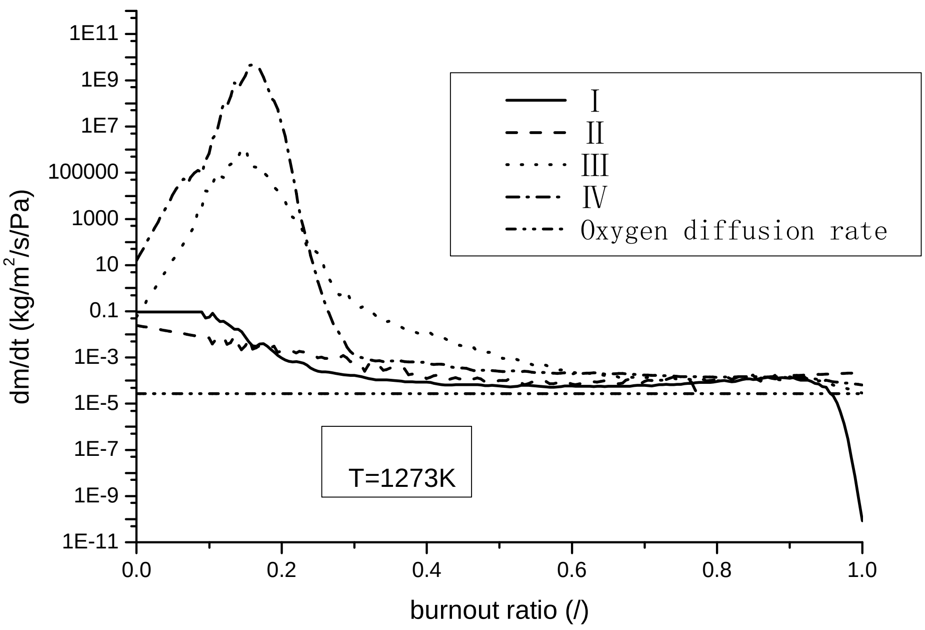


**Figure 6 The diffusion rate of the four coals predicted under the temperature1273K**

## CONCLUSION

A combustion model is provided , the model consider the apparent activation energy $E$ and the pre-exponential factor $A$ as function of burnout , its meaning has two sides : under different burnouts, combustion characteristics are different; under the same burnouts, combustion reaction chemistry dynamics constant is identical. The expressions of combustion model have analytical closed-forms. The model can reveal the mechanisms of coal combustion. Detailed study process is below: TG, DTG curves under different temperature increasing rates for an identical coal by a thermal balance TGA7 can be obtained, and the curves of the combustion rates and the temperatures varied with the burnout ratio can then be got. By the experimental data under two temperature increasing rates, the curves of the apparent activation energy $E$ and the pre-exponential factor $A$ varied with the burnout ratio can be calculated. The curves of $E$ and $A$ for four coals were obtained by the method, and the combustion rate varied with the burnout ratio for one coal under a third temperature increasing rate was calculated, which agreed well with the experimental results.

Study on combustion characteristics of blended coal by thermogravimentric analysis is made. The change trends of the combustion rates for the several coals under different constant temperature levels were predicted. Analysis results that are similar to furnace temperature are gained further . It has particular use for reference for simulating combustion process of boiler furnace.

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