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Study on Slurry Forming Properties of Coal/Modified Biomass Blending Pulping

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***Abstract:** Rice straw is an agricultural waste that is usually utilized by direct burning or landfilled which pollutes the environment. Crushing and blending into coal water slurry can effectively utilize the calorific value of rice straw and protect the environment. Due to its characteristics of strong water absorption, poor grindability, and many pores, it is not conducive for the preparation of good slurry. This paper uses temperature modification to evaluate the slurry performance of the biomass coal water slurry prepared by mixing rice straw and coal powder. The research, comparative analysis of the difference in the pulping performance of the slurry prepared by mixing rice straw before and after the modification, and the effect of the modification temperature and the modification time on the pulping performance of the slurry are summarized. The experimental results show that: the rheological index (n) of the slurry made from unmodified rice straw is the smallest, and the smallest n=0.21. Modification at different temperatures increases the rheological index of the slurry. Modification at 105°Cand 200°Cdid not improve the slurry formation performance. Modification at 250°Cand 350°Cboth increased the slurry concentration of 3g and 5g rice mixture by 3% and 2%, respectively. Moreover, the fluidity of the slurry was B, and the results of rod drop experiment showed that the water separation rate was small and the slurry was soft precipitation. Therefore, the modification effect at 250°Cand 350°Cis better.*

***Keywords:** biomass, coal water slurry, temperature modification, slurry performance*

I. INTRODUCTION

With the development of the global economy and the continuous advancement of the industrialization process, the people's living standards have been improved, and the demand for various types of energy has also been increasing. In today's energy structure in the world, oil, coal and natural gas firmly occupy the top three positions [1]. They account for 85% of the primary energy structure and are today's main energy sources. However, in the future, as energy demand continues to change, major global energy structures will also undergo major adjustments. The overall trend can be summarized as: low-carbon and renewable. From an environmental point of view, if petrochemical resources are not used cleanly, it will inevitably aggravate the "greenhouse effect" and increase the emission of polluting gases and the accumulation of solid waste, which will damage the global ecological environment. Therefore, finding environmentally clean yet efficient ways of Utilizing its Vast Energy resources has been an important issue in the direction of environmental protection in China,

In China's primary energy consumption structure, coal occupies a dominant position. According to the 2019 China Statistical Yearbook of the National Bureau of Statistics, as of the end of 2019 [2], Chinas total energy consumption (unit: standard coal) was 4.86 billion tons of standard coal, of which the total annual coal consumption in the past 8 years (unit: Standard coal) reached more than 2.7 billion tons. Therefore, it is not difficult to see that coal will still dominate energy consumption for a long time to come. However, with the development of technologies such as coal conversion and utilization, because coal contains many harmful elements and pollutants, the "greenhouse effect" caused by coal combustion has increased and the harmful gases in the atmosphere have increased [3]. Some scholars predict [4] that if the current situation is developed and no measures are taken to control it, it is estimated that by 2030, China's CO2 emissions caused by coal burning will reach about 9.2 billion tons. In this context, clean coal technology has become an important way to control coal pollution.

Biomass, among all the renewable and carbonaceous resources, is considered as a carbon neutral energy [5]. The use of biomass is favorable for reduction of CO2 emission, and as well as NOx [6]and SO2 emissions [7]. However, biomass presents lower energy density and higher transportation cost and it needs to be upgraded before utilization. It is reported that China's total biomass energy is about 1 billion tons of standard coal, including forestry and agricultural residues, domestic waste, domestic sludge and human and animal manure. The results of the Ninth National Forest Resources Inventory [8] that the forest area in China is $2.2\times 10^{8}\ hm^{2}$, of which the annual output of the remaining biomass resources from forest tending and timber harvesting is about 1.95×10^{8} t. China is rich in straw biomass resources.

According to the data [9], in 2017, the theoretical production of straw in China is about 10 × 10 8 t ' the amount of straw collectible resources is about 9×10^{8} t , and the utilization of straw is about $7.2 \times 10^{8\,t.}$ t . According to statistics [10], domestic waste treatment volume in 2017 was 3.39 × 108 t , including 2.26 × 108 ^{t} for landfill , 0.93 × ^{108} t for incineration, and $^{0.20}$ × 10 t for other treatment . ^{8} t; In 2017, the production volume of dry sludge was 10.2671 million tons, and the disposal volume was 10.059 million tons. The countries with better development of the biomass energy industry includes the United States, Germany and Japan, etc., focusing on the development of industries such as biomass fuel and biomass power generation. It is estimated that by 2035, biomass fuels will replace about half of the traditional energy in the world [11]. In order to effectively utilize biomass energy, the selection of biomass treatment methods is very important. The treatment methods mainly include biological methods, physical methods, chemical methods, and combined physical and chemical methods. The treatment method has advantages and disadvantages. Although biomass energy can be effectively utilized, there may be disadvantages such as high treatment cost, high energy consumption, and the generation of harmful substances during the treatment. For example, the commonly used mechanical pulverization treatment method of straw can be used more effectively after treatment. The advantages of this method are simple operation and easy implementation, but there are disadvantages such as large energy consumption and limited pulverization particle size [12]. At present, the more commonly used biomass disposal methods such as landfill, incineration, biogas production, etc., although landfill and incineration methods can quickly process a large amount of biomass and the treatment cost is low, but there are low biomass utilization rates, serious environmental pollution, etc. The problem is that biogas-based is relatively more environmentally friendly, with higher biomass utilization and better economic benefits. The existing biomass utilization technology has many shortcomings, so in recent years, many scholars have studied the blending of biomass and coal powder to prepare biomass coal-water slurry. Coal-water slurry is a new type of coal -based liquid fuel that emerged in the 1970s. The coal -water slurry production process (equipment) will develop toward cleanliness, high efficiency, and low energy consumption, and the choice of coal for pulping will develop toward low-cost coal, coal blending, and industrial and domestic waste. Based on the important role of fuel coal-water slurry in energy saving and emission reduction, it has broad development prospects in the fields of fuel substitution for oil, burning in urban (heating) furnaces, and gas coal-water slurry gasification. In recent years, there have been many studies on other biomass CWS. Biomass such as straw, medicinal residues, aquatic organisms, etc. are mixed with coal powder to obtain biomass CWS. At present, there are some studies on the preparation of straw coal slurry by blending wheat straw with coal. Zang Zhuoyi et al. [13] used low-temperature carbonization to treat wheat straw, studied the pulping properties of the slurry prepared before and after carbonization, and investigated the effects of carbonization temperature and wheat straw addition on the pulp properties, the results showed that the more wheat straw, the poorer the pulpability and fluidity of the pulp, but the stability was improved. With the increase of carbonization temperature, the pulpability of the pulp was gradually improved. Li Tingting [14] studied the preparation of wheat straw-coal water slurry and its pulping characteristics, still using low-temperature carbonization, and compared the differences in the pulping characteristics before and after carbonization. Carbonization treatment improves its grindability and improves the pulping performance of wheat straw-coal slurry. Li Xiang [15] used coal tar and diesel oil to modify straw to prepare modified straw coal - water slurry. Zhou Zhijun et al. [16] used drying to treat waste rice straw and then ground it into powder, which was mixed with pulverized coal in a certain proportion to prepare biomass coal-water slurry. Wang et al. [17] prepared coal slurry fuel by mixing pharmaceutical fermentation residue with pulverized coal, water and dispersant, and explored the effect of pharmaceutical fermentation residue on the slurry -forming properties of the slurry. The study showed that the slurry showed strong shear thinning. Characteristic and has high apparent viscosity, pharmaceutical fermentation residue can reduce the solid-liquid separation of coal-water slurry, thereby improving the stability of coal-water slurry. Zhang Ye et al. [18] studied the pulping characteristics of bacterial residue coal slurry, and the results showed that bacterial residue can be used as a stabilizer for CWS. Liu et al. [19] studied the Rheological behavior and stability characteristics of biochar-water slurry fuels, emphasis on the Effect of biochar particle size and size distribution. This topic mainly studies the preparation of biomass coal-water slurry by blending modified biomass and pulverized coal, and examines the slurry -forming properties of the slurry. It can not only effectively utilize the waste biomass, but also prepare a coal-water slurry with excellent slurry-forming properties. In this paper, Huainan XQ coal and rice straw were selected, and industrial analysis and ash component analysis were carried out on these two raw materials. The particle size analysis of XQ coal was further carried out to investigate the properties of raw coal and biomass characteristics. Three kinds of additives were used to prepare CWS, to select the most suitable; then we prepared biomass CWS and modified biomass CWS, and the modification method adopted was temperature modification. Furthermore, we studied the slurrying properties of biomass CWS and modified biomass CWS, comparative analysis of the differences in the slurry properties of biomass CWS before and after modification, and further investigation of the effect of modification temperature and biomass blending amount was carried. The effect of slurry forming properties.

II. EXPERIMENTAL

A. Materials

China Huainan, XQ coal and rice straw were selected, and industrial analysis analyzed according to GB/T212-2008 and GB/T213-2008 seen in Table II, and ash component analysis were carried out on these two raw materials. Coal and char samples were dried and grounded to similar particle size distributions for satisfying the requirements of slurry fuels. The particle size analysis of XQ coal was further carried out to investigate the properties of raw coal and biomass characteristics Using the BT-9300ST laser particle size distribution analyzer Fig 1-2 and Table I.

B. Preparation of Biofuels

Dry method was used to prepare biomass CWS and modified biomass CWS. Target concentration is calculated to determine the amount of water added. A burette was used to accurately measure a certain amount of water into a 250mL beaker, then a pipette to accurately take a certain number of additives from the reagent bottle into the beaker, using an electromagnetic stirrer at low speed. The two were mixed evenly, and a certain amount of biomass powder is added and stirred evenly. Due to high raw material particle size requirement in coal-water slurry preparation, the existing biomass debris in the laboratory is first screened, the biomass powder was obtained by sieving with a 200-mesh sieve. Then gradually adding 70g of coal powder into the beaker in this state, adjust the speed to 1500r/min, using a glass rod as an assistant, stir fully for 7min, and let it stand for a while to obtain a biomass coal-water slurry.

TABLE I
XQ coal particle size distribution parameters

Project	D50/μm	Volume mean diameter/μm	Area mean diameter/μm	Length Average Diameter/μm	Specific surface area/㎡/kg
XQ coal	79.95	119.90	19.10	2.12	101.30

Figure 1-2 Particle size distribution interval curve XQ coal and Cumulative curve of particle size distribution of XQ coal

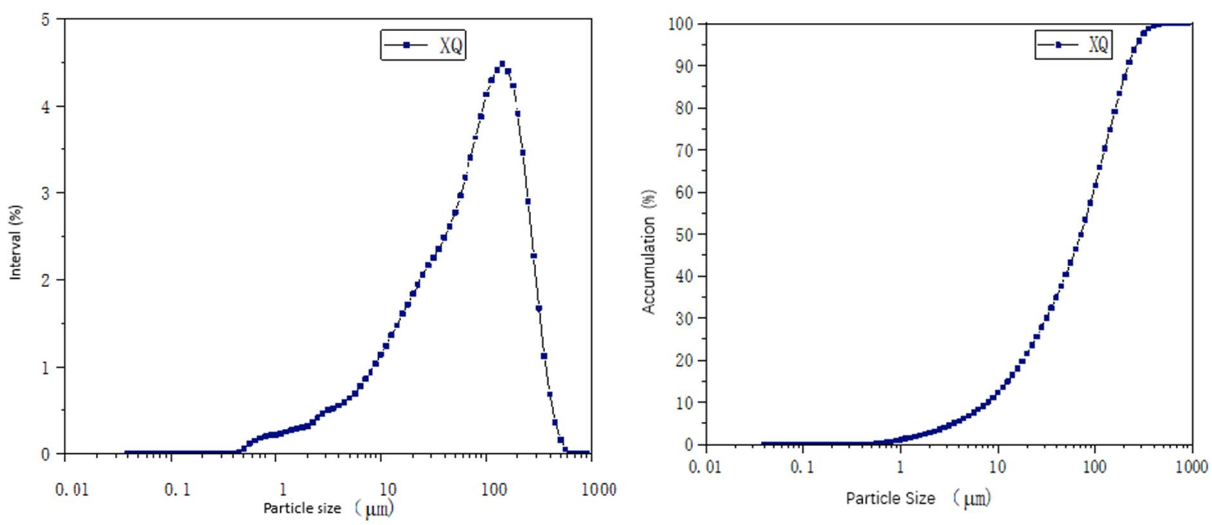

TABLE II
Industrial analysis of coal samples and biomass

Project / Sample	Industrial Analysis/%			
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}
XQ Soot	2.34	20.16	27.80	49.70
SD	6.44	26.59	54.66	12.31
T-105-1	3.47	26.27	46.61	23.65
T-105-2	2.68	27.81	44.42	24.46
T-105-3	2.51	28.25	45.05	24.82
T-200-1	3.20	27.84	65.41	3.55
T-200-2	2.18	26.18	64.29	7.77
T-200-3	1.67	25.98	63.87	8.06
T-250-0.5	1.12	37.26	39.33	22.29
T-350-0.5	0.78	38.53	37.21	23.25

C. Modification Method of Biomass coal-water Slurry

Different temperature modification methods were used to treat biomass. Biomass was placed in a constant temperature drying oven at 105 °C for 1h, 2h, and 3h respectively, and stored after cooling. sealed and labeled; repeated in a temperature-controlled drying oven at 200 ° C; put the biomass powder in a 100 mL crucible with a lid, and then put it into a muffle furnace, and control the temperature to be 250 ° C and 350 °C, respectively, the biomass was treated for 0.5h. Modified biomass was mixed with pulverized coal in a certain proportion to prepare a biomass coal-water slurry, and the slurrying performance of the modified biomass-coal-water slurry at different temperatures was studied. Note: T -105-1, T -105-2, T -105-3 are used in the text to indicate that they are placed in a constant temperature drying oven at 105°C for 1h, 2h, and 3h respectively; T -200-1, T -200-2, T -200-3 means placing the biomass in a temperature-controlled drying oven at 200°C for 1h, 2h and 3h respectively; using T -250-0.5 and T -350-0.5 means placing the biomass in a muffle furnace for 0.5h, and the control temperature is 250°C respectively and 350°C.

From Table II below that the volatile matter of biomass is relatively high, before pulping, it is necessary to determine the amount of water and additive.

The quantity of additives is 1.5‰ on a dry coal basis. The amount of water and additives can be calculated by the following formula (the quantity of additives is negligible and can be ignored) and the number of additives.:

CWS target concentration $=\frac{m_{coal}\times(1-M_{ad1})}{m_{coal}+m_{water}}$

Biomass CWS target concentration $=\frac{m_{coal}\times(1-M_{ad1})+m_{biomass}\times(1-M_{ad2})}{m_{coal}+m_{biomass}+m_{water}}$

Additive amount $=\frac{m_{coal}\times(100-M_{ad1})\times 1.5‰}{20\%}$

In the formula: m_{coal}—— mass of coal sample, g

m_{water}——Water quality, g

$m_{biomass}$——mass of biomass, g

M_{ad1}- Air-dry moisture of coal sample, %

M_{ad2}——Biomass moisture, %

D. Determination of Pulp Concentration

The concentration of CWS is determined according to the drying method in GB/T18856.2-2008. Weigh the drying weighing bottle, record its mass, and then take a CWS sample with a mass of m_0(3-5) g in Put the weighing bottle in a constant temperature drying box at 105°C for 2 hours, take it out, cool it to room temperature and weigh it, subtract the original bottle weight, and get the coal-water slurry sample for drying. After the mass is m_1, the formula for calculating the actual slurry concentration of the coal-water slurry can be obtained: C= $m_1/m_0\times 100\%$

C——Actual pulp concentration, %

m_0—— Initial mass of CWS sample, g

m_1——The mass of the CWS sample after drying, g

E. Apparent viscosity Determination

The NXS-4S type rotational viscometer was used to measure the apparent viscosity of the slurry. The viscometer was connected to the computer. Viscosity at different shear rates, set the measurement temperature to 20°C, the computer will automatically select the average value of all viscosities with a shear rate of $100s^{-1}$ is the apparent viscosity, record the apparent viscosity, and select 6 shear rates corresponding to $10s^{-1}$ to $100s^{-1}$ from top to bottom or from bottom to top Viscosity, take shear rate as abscissa and viscosity as ordinate to make viscosity diagram of coal-water slurry, and analyze the rheological properties of coal-water slurry according to the viscosity diagram.

F. Mobility Determination

The fluidity of the coal-water slurry was measured by visual inspection. According to the flow state of the coal-water slurry flowing down the glass rod, the fluidity was determined as: A grade, continuous flow; B grade, intermittent flow; C grade, flow by external force; D grade, no flow; under the same flow state, it is better to add "+", otherwise add " - ".

G. Stability Determination

The stability of the coal-water slurry was determined according to the water separation rate of the coal-water slurry and the drop rod test. Measuring the water separation rate, straightedge was used to measure the total height of the coal -water slurry and the height of the slurry. The rod experiment is to drop a glass rod with a length of 17.5cm and a mass of 30g into the test tube containing the coal-water slurry vertically and freely at a certain height. The prepared coal-water slurry was poured into a test tube, sealed with plastic wrap, and after standing for 24 hours, the water separation rate was measured and the rod drop experiment was carried out.

H. Ash Composition Analysis

According to the national standard GB/T1514-2007 coal ash composition analysis method, the ARL9800XP+ X-ray fluorescence spectrometer was used to analyze the ash composition of XQ coal and rice straw, and the results are shown in Table III.

TABLE III

Composition analysis of coal samples and biomass ash

Sample	Chemical Composition/wt%									
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Fe_2O_3
XQ Coal	0.49	0.63	28.70	43.90	0.06	0.99	0.47	2.64	1.49	2.85
SD	0.65	3.30	3.75	62.24	3.84	2.97	4.46	5.73	0.64	2.22

III. RESULT AND DISCUSSION

A. Determination of CWS Additives

According to the pulping properties of different CWS prepared with different additives, the most suitable additives were selected as the subsequent pulping additives. The measurement results of the pulping performance are seen in Table IV. It can be seen that under the condition that the additive amount of lignin, GN and GSH is 1.5‰ of coal dry basis, the maximum slurry concentration can reach 67%, the fluidity is B, and the corresponding apparent viscosity is 433.7 mPa · s, 397.3mPa · s, 496.7mPa · s, the corresponding water separation rates were 14.43%, 11.22%, and 12.04%, respectively. Combined with Figure 3, it is the viscosity diagram of CWS, showing the rheological properties of CWS, the viscosity decreases with the increase of shear rate, that is, all viscosity lines show a downward trend, and GN additives are used the viscosity line of the prepared CWS is below the other viscosity lines. It can be seen that the apparent viscosity of CWS prepared with GN additive is the smallest, the water separation rate is the smallest, and the stability is the best, so GN is the best CWS additive for this experiment.

B. Slurry Performance of Biomass coal-water Slurry

The experiment began to explore the slurry-forming properties of biomass CWS prepared by blending unmodified biomass powder and pulverized coal. impact on pulp properties. The pulping effect of the slurry is as shown in Table 5, the rheological properties of the slurry are shown in Figure 4.

The software can be used to fit the function relationship between the shear rate and shear stress of the slurry by Herschel -Bulkey model to accurately judge the rheological properties of the slurry.
The fitting formula is: $\tau = \tau_0 + K\gamma^n$
τ——shear stress, Pa
τ_0——Yield stress, Pa
K——Consistency coefficient, Pa · s
γ——Shear rate, s^{-1}
n——Slurry rheology index

The rheological characteristics of the slurry are judged by the size of n. When n<1, the slurry is a pseudoplastic fluid or a shear-thinning fluid; when n=1, the slurry is a Newtonian fluid; when n>1, the slurry is a Newtonian fluid. The bulk is an expanding plastic fluid or a shear-thickening fluid; where n becomes smaller, the more prominent the pseudoplastic characteristics of the slurry, and the more Newtonian fluid or expanding fluid characteristics are on the contrary.
For the rheological properties of Figure 4, the fitting results are shown in Table VI (the units of each parameter are the same as those expressed in figure):
It can be seen from Table V that under the condition that the GN additive amount is 1.5 ‰, the pulping properties of the slurry prepared by different blending amounts of rice straw are different. When the blending amount of rice straw and straw is 0g, 1g, 2g, 3g, 4g, and 5g, the corresponding maximum slurry concentration is 67%, 66%, 65%, 63%, 63%, and 62%, respectively. This shows that the addition of rice straw makes the slurry concentration of CWS show a downward trend. Although the slurry concentration of CWS with 3g and 4g of rice straw is the same, the apparent viscosity and water separation rate of the slurry are different. When the mixing amount of rice straw was 0g, 1g, 2g, 3g, 4g, and 5g, the corresponding slurry water separation rates were 11.22%, 4.72%, 1.92%, 0.47%, and 0.32%, respectively. With the increase of the mixing amount, the water separation rate decreased significantly, and the rod drop test results showed that all the slurries showed soft sediments except that the CWS without rice straw was a hard precipitate. It can be seen that the addition of rice straw makes the CWS stability improved. When the mixing amount of rice straw is 0g, 1g, 2g, 3g, 4g, 5g, the corresponding apparent viscosity of the slurry is 397.3mPa · s, 682.3mPa · s, 1040.2mPa · s, 1018.3mPa · s, 1380.3mPa · s, 1725.8mPa · s, which indicated that the apparent viscosity of CWS increased significantly with the increase in the amount of rice straw blended. It can be seen from Figure 4 that with the increase of the blending amount of rice straw, the apparent viscosity changes with the shear rate. When the shear rate increased from 10 s^{-1} to 100 s^{-1}, the viscosity of CWS with 1 g of rice straw was 66% and the viscosity increased from 1604 mPa · s drops to 507mPa · s, the drop is 1097mPa · s, adding 3 g of rice straw to make a biomass coal water slurry with a slurry concentration of 63 %, the viscosity is from 2436 mPa · s drops to 1065mPa · s, the drop is 1371mPa · s, it can be seen that the viscosity decreases of 1 g of rice straw is obviously smaller than that of 3 g, which may be caused by the structure and characteristics of the biomass itself.
It can be seen from Table VI that the fitting degree R^2 of the slurry rheological curve using the Herschel -Bulkey model has reached more than 0.99, indicating that this fitting method can indeed accurately judge the rheological properties of the slurry. The rheological index n is less than 1, indicating that all the slurries are pseudoplastic fluids. The more rice straw is mixed, the greater the difficulty of pulping the slurry, and the smaller the corresponding rheological index n is, that is, the pseudoplastic characteristic. more obvious.
In summary, with the increase of the blending ratio of rice straw, the stability of CWS improved, the apparent viscosity increased, the rheological index of the slurry decreased, and the pseudoplastic characteristics were more obvious. However, the slurry concentration has decreased. Therefore, it is necessary to further explore whether the addition of modified biomass is more conducive to obtaining CWS with excellent performance.

C. Slurry Performance of Temperature-modified Biomass coal-water Slurry

Pulping properties of biomass CWS prepared by blending modified rice straw with pulverized coal at temperatures of 105℃, 200℃, 250℃, and 350℃ were studied in turn, and the pulping properties of biomass CWS before and after modification of rice straw were investigated. The difference in properties and the effects of modification temperature and modification time at the same temperature on the pulping properties of biomass coal-water slurry.

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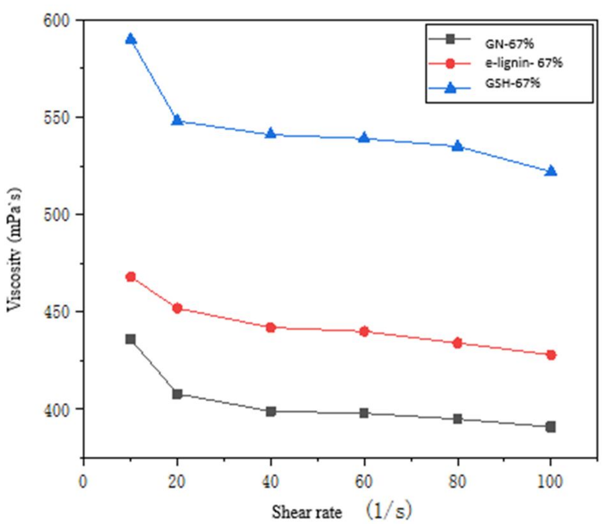
TABLE IV
Performance data of XQ coal slurry with different additives

Additive	Pulp concentration /%	Actual concentration /%	Apparent viscosity /mPa · s	Fluidity	24h Stability	
					Water separation /%	Drop test
Lignin	67	67.34	433.7	B	14.43	Hard precipitation
	66	66.38	324.0	B+	12.26	Hard precipitation
GN	67	67.43	397.3	B	11.22	Hard precipitation
	66	66.03	284.5	B+	16.51	Hard precipitation
GSH	67	67.33	496.7	B	12.04	Hard precipitation
	66	66.46	275.8	B+	16.98	Hard precipitation

Figure 3 Max slurry concentration viscosity diagram of XQ coal with different additives



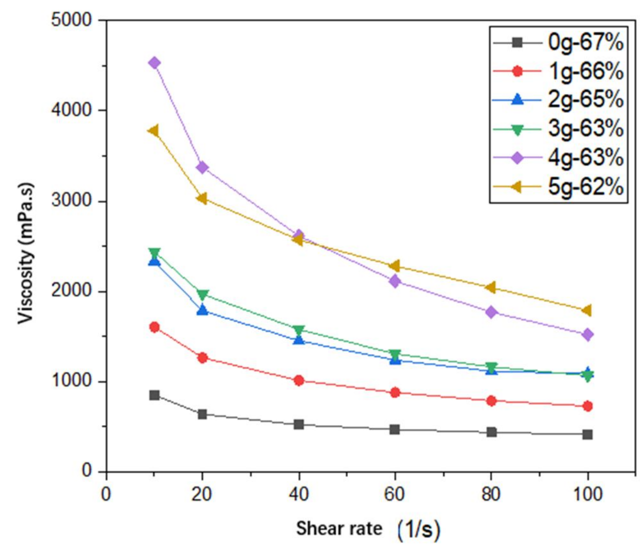


Figure 4 Rheological properties of biomass coal-water slurry

TABLE V
Slurry performance data of biomass coal-water slurry

Blending amount/g	Pulp Concentration /%	Actual Concentration /%	Apparent Viscosity /mPa · s	Fluidity	24h Stability	
					Water Separation /%	Drop test
0	67	67.43	397.3	B	11.22	Hard Precipitation
1	66	65.91	682.3	B	4.72	Soft Precipitation
2	65	64.53	1040.2	B	1.92	Soft Precipitation
3	63	63.13	1018.3	B	0.92	Soft Precipitation
4	63	62.78	1380.3	B	0.47	Soft Precipitation
5	62	62.39	1725.8	B-	0.32	Soft Precipitation

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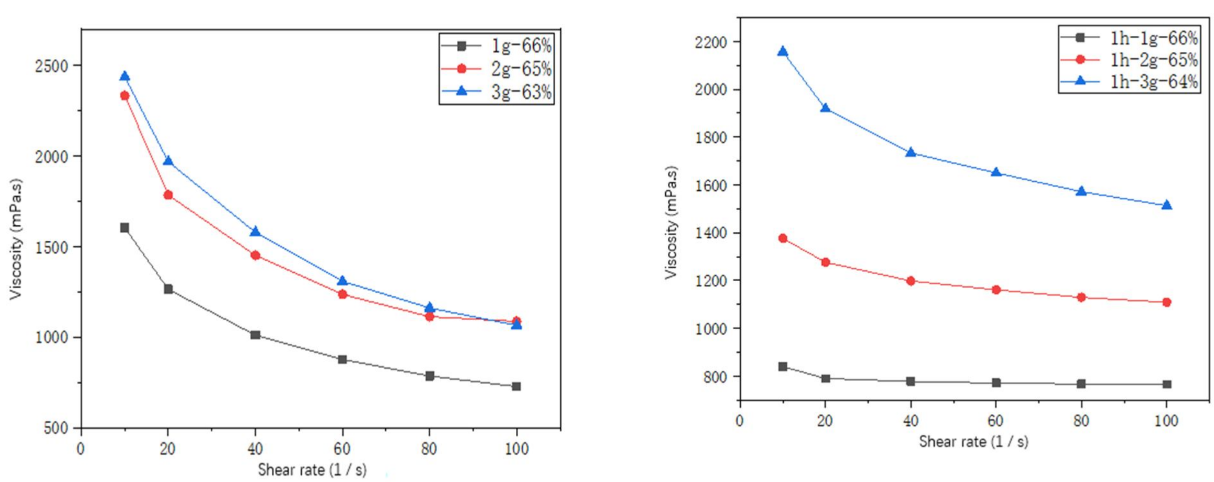
TABLE VI
Fitting parameters of slurry shear stress and shear rate

Blending amount	Pulp Concentration	τ_0	K	n	R^2
0	67	2.51249	0.88979	0.81965	0.99986
1	66	-2.13201	4.34046	0.61823	0.99992
2	65	6.2609	2.99164	0.76404	0.99655
3	63	-13.11865	11.74186	0.50327	0.99928
4	63	-132.88748	108.60562	0.21083	0.99482
5	62	-35.46915	23.23943	0.48582	0.99486

TABLE VII
Slurry performance data of slurries obtained from modified biomass at 105°C

Sample	Blend Amount/g	Pulp Concentration /%	Actual Concentration /%	Apparent Viscosity /mPa · s	Fluidity	24h Stability	
						Water separation /%	Drop Test
Rice straw	1	66	65.91	682.3	B	4.72	Soft Precipitation
	2	65	64.53	1040.3	B	1.92	Soft Precipitation
	3	63	63.13	1018.3	B	0.92	Soft Precipitation
T-105-1	1	66	66.17	787.0	B	5.66	Soft Precipitation
	2	65	65.38	1179.7	B	0.94	Soft Precipitation
	3	64	64.14	1616.3	B	0.73	Soft Precipitation
T-105-2	1	66	66.24	841.0	B	6.60	Soft Precipitation
	2	65	64.80	1199.3	B	1.87	Soft Precipitation
	3	64	64.29	1558.8	B	0.69	Soft Precipitation
T-105-3	1	66	66.27	747.5	B	5.77	Soft Precipitation
	2	65	64.56	1056.0	B	1.89	Soft Precipitation
	3	64	64.47	1418.0	B	0.56	Soft Precipitation



(a) Unmodified (b) Modification for Ihr

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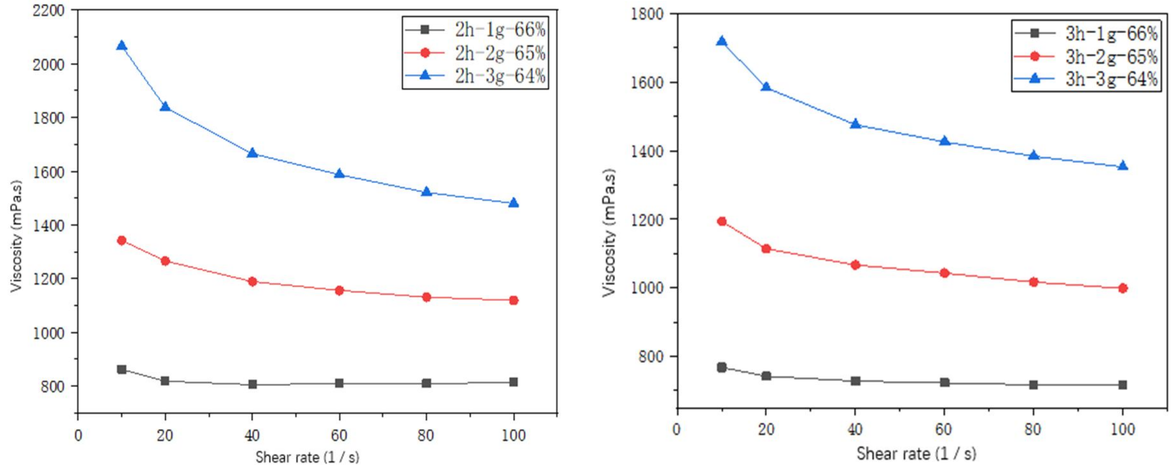

(c) Modification 2h (d) Modification 3h

Fig. 6 The rheological properties of biomass coal -water slurry modified at 105℃

TABLE VIII
Fitting parameters of slurry shear stress and shear rate

Sample	Blend Amount	Pulp Concentration	τ_0	K	n	R^2
Rice Straw	1	66	-2.13201	4.34046	0.61823	0.99992
	2	65	6.2609	2.99164	0.76404	0.99655
	3	63	-13.11865	11.74186	0.50327	0.99928
T-105-1	1	66	0.77118	0.75455	1.00100	0.99999
	2	65	0.45869	1.59633	0.92000	0.99998
	3	64	-0.55446	3.14936	0.84200	0.99989
T-105-2	1	66	1.21384	0.68399	1.03418	0.99999
	2	65	0.86577	1.43919	0.94342	0.99998
	3	64	1.30603	2.54477	0.88039	0.99998
T-105-3	1	66	0.46051	0.73205	0.99398	0.99999
	2	65	-0.26498	1.44035	0.92133	0.99996
	3	64	0.36314	2.07898	0.90628	0.99998

The effects of modification time and rice straw blending amount on biomass coal-water slurry were studied under the modification temperature of 105℃. The biomass coal-water slurry was studied, and the slurry effect of the obtained biomass-coal-water slurry is shown in Table VII. The rheological properties of the slurry are shown in Figure 6 below. The rheological properties of the slurry are further described by fitting. The specific fitting results are shown in Table VII.

The effect of 200℃ temperature modification on biomass coal-water slurry was studied. The slurry-forming effect is shown in Table IX. The rheological properties of the slurry are shown in Figure 7 below. Further fitting shows the rheology of the slurry. The specific fitting results are shown in Table X.

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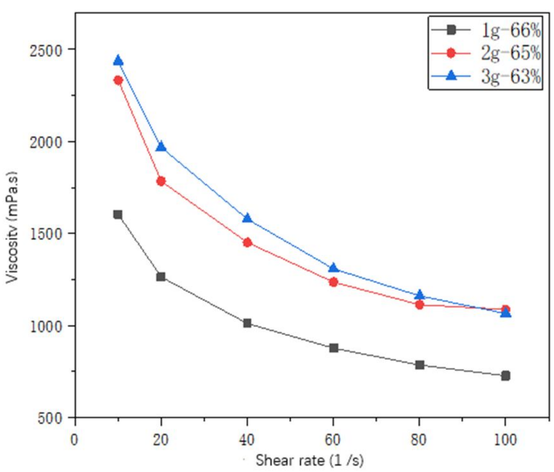
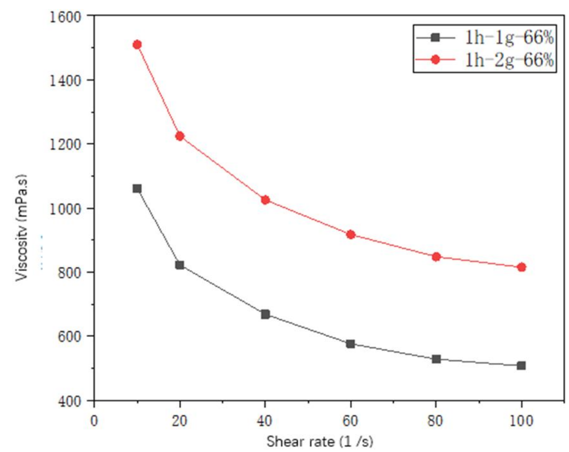
TABLE IX
Slurry performance data of slurries obtained from modified biomass at 200 ℃

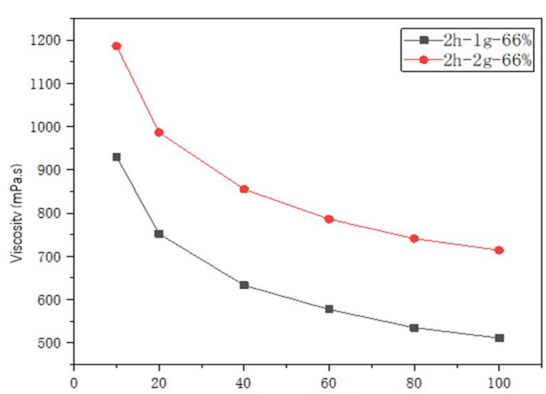
Sample	Blend Amount/g	Pulp Concentration /%	Actual Concentration /%	Apparent Viscosity /mPa · s	Fluidity	24h Stability	
						Water separation /%	Drop test
Rice Straw	1	66	65.91	682.3	B	4.72	Soft precipitation
	2	65	64.53	1040.3	B	1.92	Soft precipitation
	3	63	63.13	1018.3	B	0.92	Soft precipitation
T-200-1	1	66	66.48	488.0	B	16.67	Hard precipitation
	2	66	65.47	789.5	B	5.56	Soft precipitation
T-200-2	1	66	66.46	481.7	B	15.90	Hard precipitation
	2	66	66.17	685.3	B	3.64	Hard precipitation
T-200-3	1	66	65.85	459.5	B	10.09	Hard precipitation
	2	66	66.23	629.2	B	8.41	Hard precipitation
	3	66	66.18	869.5	B-	2.50	Hard precipitation



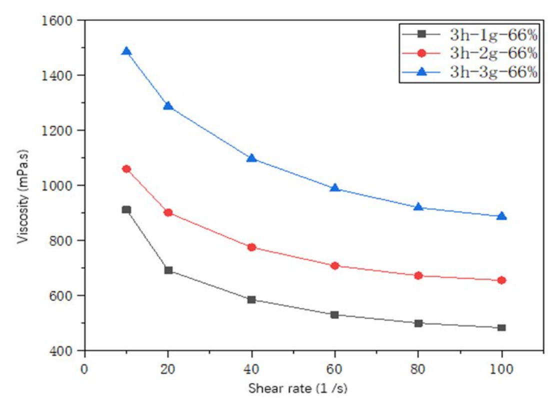
(a) Unmodified



(b) Modification 1h



(c) Modification for 2 h



(d) Modification for 3 h

Figure 7 Rheological properties of modified slurry at 200 ℃

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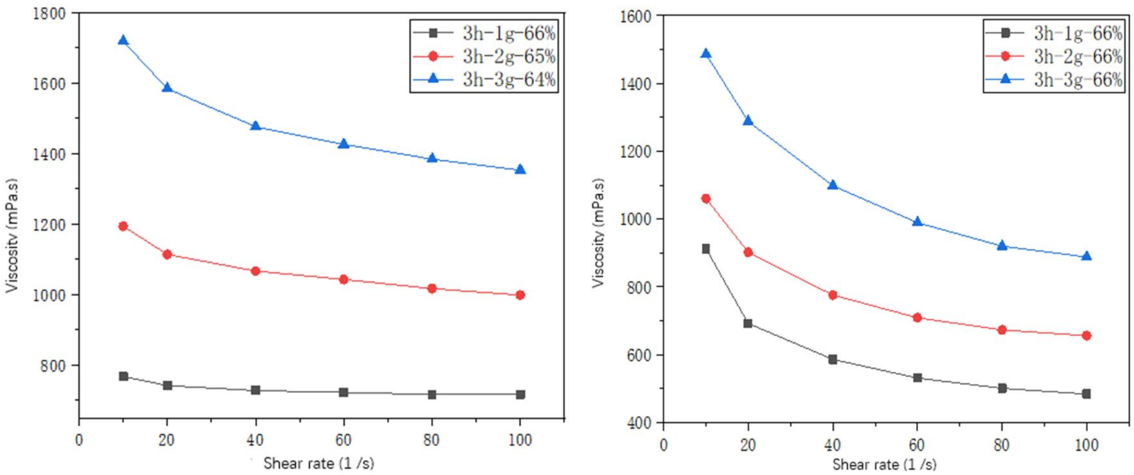
TABLE X
Fitting parameters of slurry shear stress and shear rate

Sample	Blend amount	Pulp Concentration	τ_0	K	n	R^2
Rice straw	1	66	-2.13201	4.34046	0.61823	0.99992
	2	65	6.2609	2.99164	0.76404	0.99655
	3	63	-13.11865	11.74186	0.50327	0.99928
T-200-1	1	66	2.52592	1.39739	0.76692	0.99883
	2	66	2.31379	2.10113	0.78705	0.99965
T-200-2	1	66	1.25734	1.28032	0.79495	0.99991
	2	66	1.65699	1.49118	0.83474	0.99995
T-200-3	1	66	3.13312	0.76579	0.88555	0.99985
	2	66	2.25112	1.15382	0.86878	0.99967
	3	66	0.56814	2.41699	0.77997	0.99958



(a)Modification at 105℃ (b) Modification at 200℃

Figure 8 Rheological properties of biomass coal-water slurry at different modification Temperatures.

Table XI
Slurry performance data of slurries at different modification temperatures

sample	Mixing amount of rice straw/g	pulp concentration /%	actual concentration /%	Apparent viscosity /mPa · s	fluidity	24h stability	
						water separation rate /%	drop test
rice straw	3	63	63.13	1018.3	B	0.92	soft precipitation
	5	62	62.39	1725.8	B-	0.32	soft precipitation
T-250-0.5	3	66	66.24	902.0	B	1.01	soft precipitation
	5	64	64.38	825.3	B	0.48	soft precipitation
	7	62	61.81	878.8	B	2.11	soft precipitation
T-350-0.5	3	66	66.36	1322.2	B	0.98	soft precipitation
	5	64	64.26	996.8	B	0.45	soft precipitation
	7	63	63.26	996.3	B	1.43	soft precipitation

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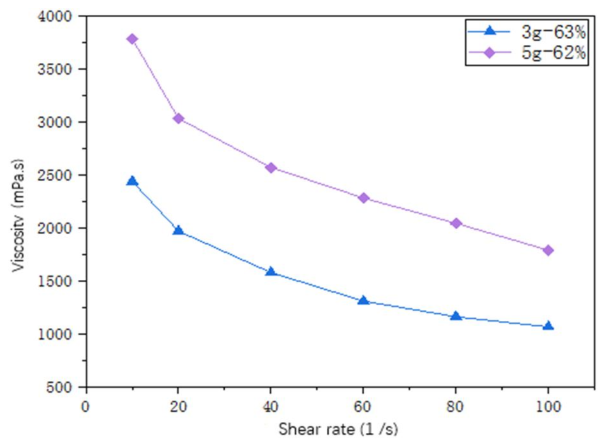
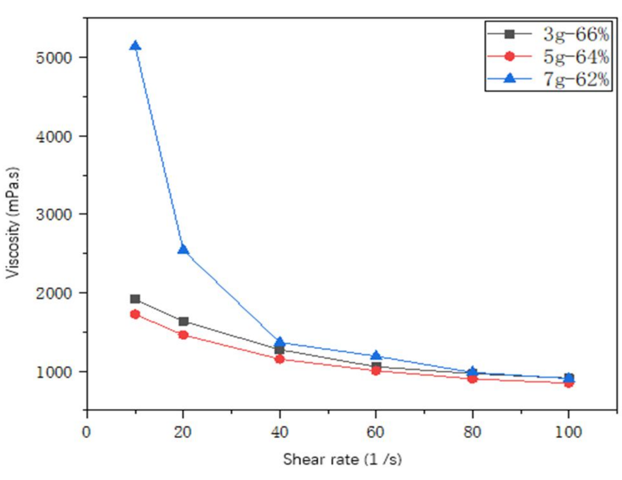
Table XII Fitting parameters of slurry shear stress and shear rate

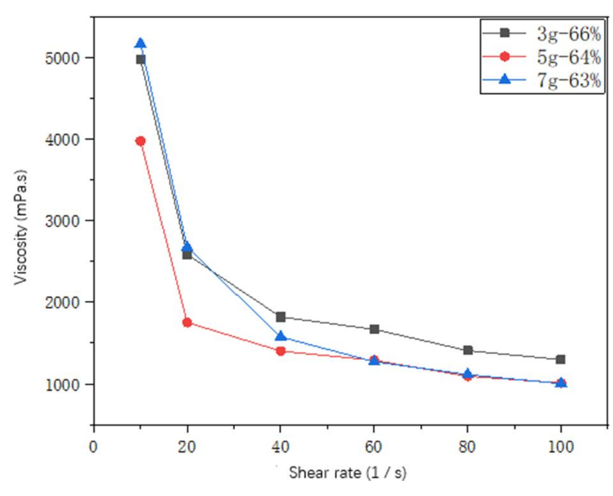
Sample	Blend amount	Pulp Concentration	τ_0	K	N	R^2
Rice straw	3	63	-13.11865	11.74186	0.50327	0.99928
	5	62	-35.46915	23.23943	0.48582	0.99486
T-250-0.5	3	66	-1.74093	5.11079	0.62733	0.9971
	5	64	-3.41355	4.98137	0.62268	0.99953
	7	62	48.32734	0.03202	1.56419	0.95659
T-350-0.5	3	66	35.75312	1.16786	0.95657	0.97701
	5	64	27.91891	0.66483	1.02624	0.95051
	7	63	47.65643	0.15017	1.27655	0.99416



(a) Unmodified



(b)Modification at 250℃



(c) Modification at 350℃

Figure 9 The rheological properties of the slurry at different modification temperatures

The mixing of rice straw and coal powder can significantly improve the stability of CWS, which may be due to the fact that the rice straw itself contains cellulose, lignin and other main components, so that the particles in the CWS are not easy to settle, thus improving the efficiency of the slurry. body stability. With the increase of the mixing amount of rice straw, the slurry concentration decreased gradually, and the rheological index n decreased gradually, and the pseudoplastic characteristics of the slurry became more obvious

Comparing the difference in the slurry properties before and after the drying oven modification, the modification at 105 °C makes the rheological index n of the slurry increase, and the modification at 200 °C makes the rheological index n of the slurry slightly increase, that is, no modification. The pseudoplastic characteristics of the slurry prepared from rice straw were the most obvious, and the n at 105℃ was greater than 200℃, that is, the pseudoplastic characteristics of the slurry prepared at 200℃ were more obvious. Treating rice straw at 105°C had little effect on other pulping properties of the pulp. Treating rice straw at 200°C increased the pulping concentration of the pulp, but the stability of the pulp became worse. When the modification temperature was 105°C, with the increase of the blending amount of modified rice straw, the change trend of the pulping properties of the slurry was the same as that in conclusion 1, but it was different at 200°C. When 1g was increased to 2g and 3g, the slurry concentration was both 66%, and the change trend of other properties was the same as Conclusion 1.

The pulping properties of the slurries prepared by the modified rice straw at 250℃ and 350℃ were compared with those prepared by the unmodified rice straw. The slurry concentration was improved, and the slurry with 7 g of rice straw was added, and the slurry concentration was not too low, 62% and 63% respectively; for the rheological properties, the slurry prepared from unmodified rice straw had the most pseudoplastic characteristics. Obviously, the rheological index n of the slurry prepared by adding 3g and 5g of rice straw to the modified rice straw at 250℃ increased slightly, and $n<1$, the slurry showed pseudoplastic characteristics, while the slurry with 7g of rice straw was added. The rheological index $n>1$; 350 ℃ modified rice straw, with the increase of the amount of rice straw, the rheological index n value of the slurry increases, only the slurry prepared by adding 3g rice straw has $n < 1$, the slurry The slurries exhibited pseudoplastic characteristics, and the n of other blending amounts were all > 1, showing the characteristics of shear thickening; the other pulping properties were less affected by the modification, and still had good fluidity and stability.

IV. CONCLUSION

Comparing the pulping properties of CWS and biomass CWS, it can be seen that the fluidity of the slurry is good. The smaller the rheological index, and all $n<1$, the more obvious the pseudoplastic characteristics of the slurry, the better the fluidity and stability of the slurry, but the lower and lower the slurry concentration. The addition of rice straw is not conducive to the preparation of high-concentration biomass CWS, so the preparation of biomass CWS by temperature-modified rice straw is further explored.

Modified rice straw at 105℃ and 200℃ were compared with the pulp prepared by the unmodified rice straw. The results showed that the temperature modification at 105℃ increased the rheological index n of the slurry, and 200 ℃ temperature modification makes the slurry rheological index n slightly increase, that is, the pseudoplastic characteristics of the slurry prepared from unmodified rice straw are the most obvious, and the n at 105 ℃ is greater than 200 ℃, that is, the slurry prepared by treatment at 200 ℃ is the most obvious. Plasma pseudoplastic features are more obvious. The other pulping properties of the slurry prepared by treating rice straw at 105 °C were good. Although the pulping concentration of the pulp was improved when the rice straw was treated at 200 °C, the stability of the pulp was deteriorated. Therefore, the temperature modification at 105℃ and 200℃ did not effectively improve the pulping properties of the slurry.

It is feasible to use the muffle furnace temperature modification method to prepare biomass coal-water slurry. The rheological index n of the slurry prepared by the modification of rice straw at 250 °C and 350 °C increases. For the same modification temperature, The more the blending amount of rice straw, the greater the rheological index n. Under the same blending amount of rice straw, the higher the modification temperature, the greater the rheological index n of the slurry. The slurry concentration of 3g and 5g increased by 3% and 2% respectively, and the fluidity and stability of the slurry were good. Therefore, the modification effect at 250℃ and 350℃ was better.

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