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Preparing coal slurry from coking wastewater to achieve resource utilization: Slurrying mechanism of coking wastewater–coal slurry

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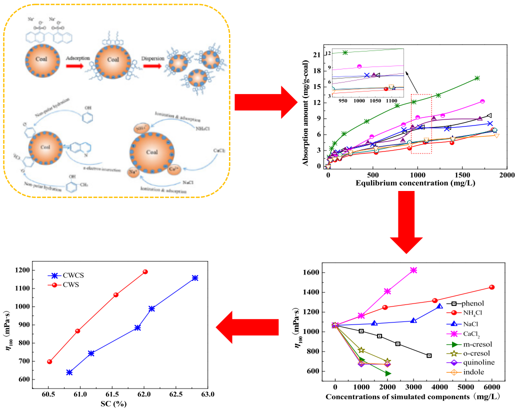
HIGHLIGHTS

- The coking wastewater was beneficial to the slurrying of the coal slurry.
- Competitive adsorption between the organic components of wastewater and the additive.
- Organic components influence the Zeta potential of coal and surface tension of water.
- Cations increased the additive adsorption but decreased the slurrying capability.

GRAPHICAL ABSTRACT



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ABSTRACT

Coking wastewater is used to prepare coal slurry, which can be used as combustion and gasification fuel. This promising technology simultaneously achieves resource utilization and wastewater management. Slurrying properties are essential to the industrial application of coal slurry. These properties are considerably influenced by coal surface properties and the adsorption of an additive by coal. In this study, the effects of the internal components (e.g., phenol, ammonia nitrogen, and metal ions) of coking wastewater on the adsorption of an additive by coal and on coal surface properties were measured. Results showed that the competitive adsorption between phenol and the additive reduced the amount of additive adsorbed on coal. However, phenol acted as an additive to improve the wettability of coal particles. Cations (Ca^{2+}, NH_4^+, and Na^+) adversely affected the slurrying because they weakened the negative charges of coal. Furthermore, a large amount of water was adsorbed due to the ionic bonding effects, thereby reducing the free water in the coal slurry system. The maximum slurrying concentration of CWCS was 0.8 percentage points higher than that of CWS, suggesting that coking wastewater enhanced the slurrying capability of the coal slurry by integrating the various effects induced by the different internal components.

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Nomenclature

COD	chemical oxygen demand
CWCS	coking wastewater–coal slurry
CWS	common coal water slurry
GC–MS	gas chromatography–mass spectrometry
NH_3-N	ammonia nitrogen
NNO	methylene bis-naphthalene sulfonate
SC	solid concentration
SC_{max}	the SC of coal slurry when its η_{100} reaches 1000 mPa·s
λ_{max}	the maximum absorption wavelength
η_{100}	slurrying viscosity (the average apparent viscosity of the coal slurry at a shear rate of 100 s^{-1})
Γ	adsorption amount of additive by unit mass of coal (dry basis), mg·g^{-1}
c_0	concentration of the original additive solution, mg·L^{-1}
c_1	equilibrium concentration remaining in the solution after adsorption, mg·L^{-1}
V	volume of additive solution, L
m	mass of the coal (dry basis) used to adsorb additive, g

1. Introduction

1.1. Coking wastewater and its treatment

Coking wastewater is generated from coke quenching and coking gas purification during coking (Xie et al., 2010). Coking wastewater has a complex composition and is abundant in refractory organic matters, including phenols, polycyclic aromatic hydrocarbons, and cyanide (Zhang et al., 2012), all of which are highly toxic to most microorganisms. Improper disposal of coking wastewater results in serious environmental pollution and poses a threat to human health and sustainable social development because of the high pollution potential of coking wastewater.

Currently, coking wastewater is treated by combining biological denitrification, chemical oxidation, adsorption, and coagulation methods (Na et al., 2017). However, these approaches encounter many problems, such as overloading of wastewater treatment equipment, high values of chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) after treatment, intensive investment and large area required by denitrification unites, and high operation costs. The cost of coking wastewater treatment is expected to increase further as environmental protection awareness continues to grow and strict requirements for wastewater emission are enforced. Coking wastewater is sometimes reused as water for coke quenching, coke gas cooling, aeration pool defoaming, coal washing, and coal dust suppression to reduce treatment costs. Coking wastewater is also utilized instead of clean water to prepare coal slurry, which can be used as an alternative fuel to oil (Dmitrienko and Strizhak, 2017). This promising technology simultaneously achieves resource utilization and wastewater management and offers significant economic and environmental advantages.

Coal slurry is a heterogeneous liquid–solid suspension consisting of 60%–70% coal, 30%–40% water, and a small amount of additives (surface active agents) (Liu et al., 2014). Coal slurry can be used as an alternative liquid fuel to oil, and it provides comprehensive benefits to environmental protection and energy conservation because of its low transportation cost, low combustion pollutant emissions, and high combustion efficiency (Nodelman et al., 2000). Therefore, coal slurry has a good application potential in China.

1.2. Previous study on waste—coal slurry

Waste—coal slurry is prepared by mixing waste, coal, water and a bit of additive. The waste included municipal sewage sludge (Li et al., 2009), oily sludge (Xu et al., 2014a), and drugs residue (J.Q. Wang et al., 2018). Waste—coal slurry provides a new treatment method for the energy-containing waste (Nyashina et al., 2018a). However, the effects of these wastes on CWS are mainly depended on its solid materials.

A few studies have investigated coal slurry preparation from industrial wastewaters, such as papermaking black liquor (Zhan et al., 2010), petrochemical wastewater (Nyashina et al., 2018a), engine oil waste (Chernetskiy et al., 2018), motor oil waste (Nyashina et al., 2018b), petrochemical oil water emulsion (Kuznetsov et al., 2018), thermoelectric plant wastewater (Vershinina and Strizhak, 2016), oil field wastewater (Xiang et al., 2016), and alcohol fermentation wastewater (Shao et al., 2012), etc. However, the composition of these wastewaters differs considerably from that of coking wastewater, which contains high COD, phenols, and cations. Besides, the above references mainly focused on the macroscopic properties, including viscosity, rheological behavior, storage stability, and combustion performances of the coal slurry.

Only a few studies have explored the slurrying of coking wastewater–coal slurry (CWCS). Zhao and Zuo (2008) discovered that coal slurry prepared from coking wastewater possesses lower viscosity and better stability than that produced from tap water. Mu et al. (2005a, 2005b) found that the ammonia nitrogen in coking wastewater adversely affects the rheological properties of coal slurry. When the ammonia concentration is increased, the apparent viscosity of coal slurry increases. Fluidity worsens, but stability improves. By contrast, phenols decrease the viscosity and improve the slurrying capability of CWCS. However, the microscopic slurrying mechanisms have been seldom involved.

1.3. The goal of the present study

CWCS prepared from coking wastewater can be used as combustion and gasification fuel (Xu et al., 2014b). The slurrying performance of CWCS and the effects of various internal components of coking wastewater on performance must be investigated prior to industrial application because they significantly influence the preparation, transportation, atomization, gasification, and combustion behavior of coal slurry fuels (Zhao et al., 2014). Previous studies demonstrated that the internal components of coking wastewater influence the slurrying of CWCS. Adsorption significantly affects the slurrying of coal slurry (R.K. Wang et al., 2018). When coking wastewater is used to prepare coal slurry, abundant internal components are adsorbed by the coal particles, and this adsorption affects coal–additive adsorption and coal surface characteristics (Liu et al., 2017). However, only a few studies have explored these issues, and the slurrying mechanisms of CWCS remain unclear. In the present study, the slurrying mechanisms of CWCS were discussed based on the effects of the various internal components of coking wastewater on coal surface properties and on the adsorption of additives by coal particles. The obtained results can serve as a reference for the preparation and utilization of CWCS and recycling of coking wastewater.

2. Experiment and method

2.1. Materials

Bituminous coal was selected, and the proximate and ultimate analyses are shown in Table 1. Naturally dried coal was pulverized and

Table 1
Proximate and ultimate analyses of coal.

Sample	Proximate analysis (%)				Ultimate analysis (%)					$Q_{gr,ad}$ (kJ/kg)
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C_{daf}	H_{daf}	N_{daf}	$S_{t,daf}$	O_{daf}	
Coal	4.37	27.28	28.03	40.32	74.04	4.58	1.58	1.04	18.76	20,049

Note: M, A, V and FC respectively refer to moisture, ash, volatile and fixed carbon; C, H, N, S and O respectively refer to elemental carbon, hydrogen, nitrogen, sulfur and oxygen; ad refers to air dried basis; daf refers to dry and ash free basis; Q_{gr} refers to high calorific value.