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Pilot-scale investigation on slurrying, combustion, and slagging characteristics of coal slurry fuel prepared using industrial wasteliquid

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HIGHLIGHTS

- Wasteliquid is used as a substitute for clean water to prepare coal slurry.
- The combustion characteristics of CWLS are studied in a pilot scale furnace.
- Wasteliquid enhances the slurryability of the coal and saves the additive agent.
- Wasteliquid improves the ignition and combustion performances of coal slurry.
- The metal ions in the wasteliquid reduce the SO_2 and NO_x emissions.

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ABSTRACT

The large amount of industrial wasteliquid generated during various industrial processes has raised serious environmental issues. A coal–wasteliquid slurry (CWLS) is proposed to dispose such wasteliquids, which are used as a substitute for clean water in the preparation of a coal-based slurry fuel. By the use of this method, a significant amount of clean water is conserved, and the environmental problems caused by wasteliquid discharge are resolved. However, the high content of organic matters, alkaline metal ions, and sulfur and nitro compounds considerably affects the slurrying, combustion, slagging, and pollution emission characteristics of CWLS. In this study, these characteristics are experimentally studied using a pilot-scale furnace. The results reveal that, compared with conventional coal–water slurry (CWS), CWLS exhibits a good performance with respect to slurrying, combustion, and pollution emission, i.e., low viscosity, rapid ignition, high flame temperature, high combustion efficiency, and low pollution emission. CWLS has a relatively low viscosity of 278 and 221 mPa·s and exhibits shear-thinning pseudo-plastic behavior without the use of any additive agent. In contrast, CWS requires the use of an additive agent to achieve good fluidity, and its viscosity is 309 mPa·s. The maximum flame temperature of the two CWLSs (CWLS-A and CWLS-B) is 1309.0 and 1303.1 °C, respectively, and their respective combustion efficiency is 99.61% and 99.42%. The values of both these parameters are greater than those obtained in the case of CWS. However, the alkaline metal ions in the wasteliquid lead to a considerable slagging status. This status improves significantly after turning down the operating load.

1. Introduction

Coal–water slurry (CWS), which approximately consists of 65–70% coal, 30–35% moisture, and a little additive, is a coal-based clean fuel that can be used as a substitute for oil [1,2]. It not only exhibits similar performances as oil in terms of pumping, storing, and atomizing, but can also be used as an alternative fuel with high combustion efficiency in power station boilers, industrial boilers, and furnaces. Further, NO_x emissions can be reduced during the combustion of CWS, because the furnace temperature is low compared with that in the case of the combustion of oil and pulverized coal [3].

Along with the development of industries, the emissions of various industrial wasteliquids, sewage sludge, and waste residues have increased rapidly, particularly the emission of concentrated non-biodegradable toxic organic wasteliquids, which are generally discharged into the environment from various industries such as food, fermentation, slaughter, textile, paper, rubber, plastic, cosmetics, pesticide, petrochemical, and domestic sewage. When discharged into the environment, organic wasteliquids cause serious environmental pollution. The disposal of such volumes of organic wasteliquids is a long-standing problem in the field of environmental protection. Therefore, reliable methods are very necessary for the disposal of organic wasteliquids.

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A considerable amount of effort has been devoted to the effective disposal of organic wasteliquid and the removal of toxic matters from wasteliquids. For the disposal of organic wasteliquids, various treatment techniques are available such as adsorption [4], chemical precipitation [5], liquid–liquid extraction [6], ion exchange, coagulation [7,8], reverse osmosis [9], electrolysis, membrane process [10], glow discharge plasma [11], full cell [12], and oxidation [13,14]. However, building a complete set of wasteliquid-disposing technology and matching installation, which meets national standards, needs high investment and running costs. Numerous enterprises are unable or unwilling to invest the significant money to treat their wasteliquid. This is a main reason for serious environmental pollution in China. Therefore, exploring for a low cost way of disposing wasteliquid is of great concern. Coal–wasteliquid slurry (CWLS) is considered an effective, efficient, and economic method for the disposal of wastewater. Wasteliquids are used as a substitute for clean water in the preparation of a coal slurry fuel, thereby saving a considerable amount of clean water. It usually contains a certain amount of lignin, semicellulose, sugar, organic acid, and sulfonic substances, which are active matter or active-group-containing polymers. When the wasteliquid is used for preparing coal slurry, these active functional groups act as surfactants and improve the surface activity and wettability of the coal particles; thus, the coal particles are well dispersed in suspension [15,16]. Therefore, all or part of the chemical additive agent needed for slurrying can be replaced, and the slurrying cost can be reduced [17,18]. During the combustion of CWLS, the caloric value of the organic matter in the wasteliquid is utilized sufficiently. The organic matters can also improve the ignition and burnout performances of the slurry fuel in boilers. At the same time, the emissions of some pollutants such as SO_2 and CO are reduced because of sulfur-retention components of the wasteliquid and the complete combustion of the coal particles [19]. Hence, the CWLS technique provides a low-cost solution for pollution problems caused by wasteliquids, leads to savings of a considerable amount in terms of pollution treatment fees, and provides large volumes of cheap fuel for enterprises. The CWLS technique reduces the environmental hazards of the wasteliquid discharged by various industries, broadens the disposal ways of wasteliquids, and substantially reduces the production costs of the enterprises.

However, wasteliquids contain a high concentration of organic materials, metal ions, and sulfur and nitro compounds, which significantly influence the slurrying, combustion, slagging, and pollution emission properties of CWLS. Thus far, there have been no reports on the pilot-scale combustion and slagging properties of CWLS. Therefore, the ignition characteristics and combustion, slagging, and pollution emission properties of two CWLSs are investigated using a pilot-scale horizontal cylindrical furnace in this study. The obtained results provide a foundation for the disposal of industrial wasteliquids and the industrial application of CWLS and can be used as a reference for the optimal operation of full-scale boilers.

2. Experimental section

2.1. Materials

Two chemical wasteliquids from Beijing Yanshan Petrochemical Company were used for preparing CWLS. The two wasteliquids (wasteliquid A and wasteliquid B) were caustic liquids obtained from two typical processes in petrochemical field, ethylene separation from dry gas and petroleum refining, respectively. Before being discharged, they must be processed for environmental safety. The quality analysis of these two wasteliquids is shown in Table 1.

Table 1
Wasteliquid quality analysis (Unit: mg/L).

Test items	Wasteliquid A	Wasteliquid B
K	37.9	44.3
Na	1.13×10^3	2.66×10^3
Ca	123	154
Mg	<0.02	<0.02
Cu	<0.01	<0.01
Pb	<0.50	<0.50
Ni	<0.01	<0.01
Cr	<0.01	<0.01
Cd	<0.03	<0.03
V	0.096	<0.01
Mn	0.097	0.129
Co	<0.120	<0.120
SO_4^{2-}	2.8×10^3	9.6×10^3
Cl^-	27	9.78
S^{2-}	0.411	0.087
Ammonia nitrogen	24	19.5
Volatile phenol	17.4	7.7
TDS	1.6×10^4	1.5×10^4
COD	1.06×10^3	596
Total nitrogen	42.8	27.8

TDS is the total dry solid content; COD is the chemical oxygen demand.

Three coal slurry samples were prepared using tap water, wasteliquid A, and wasteliquid B, and their respective names are CWS, CWLS-A, and CWLS-B, respectively. The coal used was bituminite from Datong, Shanxi province, China.

Because of the lack of an active agent, tap water could not disperse the coal particles sufficiently, and the coal–water mixture could not flow. A little amount of a chemical additive agent (0.8% of the coal) was added to prepare good-fluidity coal slurry. In contrast, the coal slurry prepared using wasteliquid could flow easily; thus, no additive agent was added during slurrying.

The proximate and ultimate analysis of the three slurry samples is given in Table 2. The solid concentration, equal to $(1 - M_t)$, of the three slurry samples is similar: 63.35% (CWS), 63.27% (CWLS-A), and 63.20% (CWLS-B. Because wasteliquids contain a certain amount of TDS, COD, and S and N components, the corresponding CWLSs show a higher content of FC_d, V_d, and $S_{t,d}$ and N_d elements than CWS. Between the two wasteliquids, wasteliquid A contains a higher content of TDS, COD, and N components; thus CWLS-A shows a higher content of FC_d, V_d, and N_d elements. On the other hand, wasteliquid B contains a higher content of SO_4^{2-}, and thus, CWLS-B shows a higher content of $S_{t,d}$ elements.

The high content of alkaline metal ions such as K, Na, and Ca in the wasteliquids considerably affects the ash fusion temperature and slagging during the combustion of the coal slurry. The ash fusion temperatures of the three slurry samples are shown in Table 3. The ash fusion temperatures of coal slurry samples prepared by using the wasteliquids evidently decrease. As a result, it is considerably easy to melt fly ash particles, and the slagging status is then aggravated. Moreover, CWLSs have a smaller difference between the deformation and fluxion temperatures (FT–DT) than CWS; thus, the fly ash of CWLSs is easier to transform from the deformation to the flow state, i.e., the melted ash could easily adhere to the boiler/furnace heating surfaces.

2.2. Slurrying properties

The rheological properties of the coal slurry were determined using a rotational viscometer (HAAKEVT550, Thermo, USA). The temperature was maintained constant within (20 ± 0.5) °C and was controlled using a water bath. During the measurements, the slurry samples in the viscometer underwent three stages: (1) increasing shear rate stage, in which the shear rate was increased