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Surface characteristics and wettability enhancement of respirable sintering dust by nonionic surfactant

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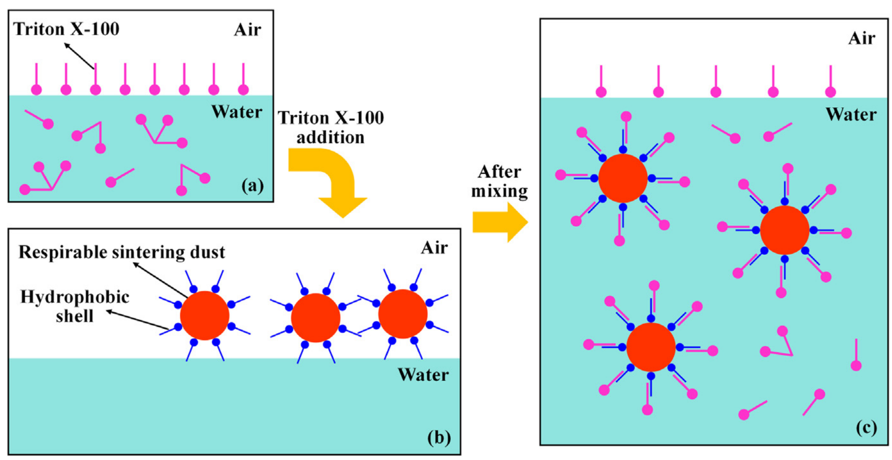
HIGHLIGHTS

- Surface characteristics of respirable sintering dust were first examined in details.
- Respirable sintering dust's strong hydrophobicity caused by a hydrophobic shell.
- Triton X-100 can greatly enhance respirable sintering dust's wettability.
- Results shed light on dust control and utilization of respirable sintering dust.

GRAPHICAL ABSTRACT



Respirable sintering dust, as a typical industrial waste, was found to be covered by a hydrophobic shell consisting of organics with *n*-alkyl chains and/or aromatic groups. And this dust can be sufficiently and efficiently wetted by Triton X-100 after moderate mixing, achieving by adsorption between their hydrophobic tails.

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ABSTRACT

Plenty of respirable sintering dust are generated in ironmaking process and part of this hazardous particle easily escaped from electrostatic precipitators, becoming Particulate Matter 10. Previous studies are usually focused on the comprehensive recovery of this dust, however, its wetting, which was an essential procedure in many industrial processes, has long been a challenge due to its strongly hydrophobic property. The current study investigated the origin of its hydrophobicity through wettability tests, dynamic contact angle analysis, Fourier transform infrared spectrophotometer and X-ray photoelectron spectroscopy, with the goal of enhancing its wettability. The results revealed for the first time that the hydrophobicity of respirable sintering dust was attributed to a hydrophobic shell consisting of organics with *n*-alkyl chains and/or aromatic groups and bonding by hydrophilic functional groups. Further, results of response surface methodology with central composite design and dynamic contact angle analysis demonstrated that increasing agitation strength, such as stirring speed and time, can improve the wettability of respirable sintering dust, while the largest wettable ratio of 95.3% was obtained by stirring with 0.2% Triton X-100. Eventually, a possible wetting mechanism was mainly concluded as nonionic surfactants adsorbing with the hydrophobic shell on respirable sintering dust surface via its

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hydrophobic tail and leaving its hydrophilic head groups exposed to water, achieving sufficiently and efficiently wetting. The adsorption experiments and surface analysis results implied that the adsorption process for Triton X-100 onto respirable sintering dust is favorable and governed by physisorption. This study provides an effective method on the wetting of respirable sintering dust, which is essential for its treatment such as dust control and hydrometallurgy.

1. Introduction

The sintering process is a core part of the integrated iron and steelmaking process route throughout the world [1]. The process is carried out by mixing iron ore with other additives and correcting the blend moisture before entering a pelletizer to produce moist micropellets which are charged on a moving strand followed by combusting. Air is drawn through the bed by an induced draught fan to sustain the combustion [2]. Meanwhile, a plenty of waste gas leaves the bed and passes through a series of wind boxes beneath the sinter strand, and thence through an electrostatic precipitator to effect de-dusting of the waste gas before being released to the atmosphere [3], capturing most of the sintering dust. This dust which cannot be recycled in the sintering process has to be disposed of in landfill sites [4].

The amount of sintering dust was increased with the huge steel production, which will occupy plenty of lands and cause different degrees of environmental pollution. Furthermore, most of the sintering dust particles with a diameter below 10 μm are classified as Particulate Matter (PM) in environmental standards, hence, it also can be named respirable sintering dust [5,6]. Even though the electrostatic precipitator has separated most of the sintering dust from the waste gas, part of these particles still escaped [7]. They typically contain Pb and Cd and are able to settle in the lungs where they are hazardous to health and they often cause severe diseases [8,9]. Therefore, it is absolutely imperative to conduct a thorough research on this waste.

The wettability of finely divided solids (powders and agglomerates) is an essential component in a number of practical applications and processes such as dissolution, dispersion, granulation, coating, drying, etc. [10,11]. When pouring powder onto static water, the first hurdle to overcome is the air–water interface [12]. Therefore, these surface physical properties of sintering dust are of great concern for treatment and utilization because the spreading of liquids on solid substrates is of interest to many practical applications and industrial processes such as flotation, hydrometallurgy and dust control [13]. Take the dust control for an example. Water spray is a universal controlling method used for dust suppression aimed to decrease the content of respirable dust in the air [14,15]. The primary condition is to wet the particles by water or other liquid. Therefore, the wetting ability of the dust may have a significant influence on dust suppression efficiency by water spraying method [16,17]. Unfortunately, the sintering dust particles tended to agglomerate together and floated on the surface of water after being added into water [18,6]. These phenomena indicate that some substance might be adsorbed on the surface of the sintering dust, which prevent it from being wetted. However, most studies concerning sintering dust are focused on comprehensive utilization of valuable components in it [19–21]. There is a lack of research on the surface characteristics of sintering dust, as well as its wettability.

Considering surfactants are ideal reagent to modify the surface of the mineral particles, which are important for regulating the surface tension, wetting, dispersion and rheology [22,23], they might be having efficient influences on the wetting of respirable sintering dust. In this paper, the surface physical properties of the dust were analyzed by contact angle analysis, Fourier transform infrared spectrophotometer (FT-IR) and X-ray photoelectron spectroscopy (XPS). Then the effects of stirring conditions on the wettability of sintering dust were studied and these stirring parameters were evaluated by response surface methodology with central composite design. Furthermore, wettability experiments and dynamic contact angle analysis were performed on the wetting behavior of respirable sintering dust in the presence of one cationic, one anionic and one nonionic surfactant used in a wide range of concentrations. Based on these results and adsorption experiments, a possible mechanism was brought up to explain the wetting process of respirable sintering dust, which was an essential procedure in many industrial processes.

2. Material and methods

2.1. Materials and reagents

The sintering dust samples were received from the sintering plant at the Panzhihua Iron & Steel (Group) Co., Ltd. in Sichuan Province, China. Analytical grade surfactants, cetyltrimethylammonium bromide (CTAB), Sodium dodecyl sulfate (SDS) and Triton X-100 (TX-100, $C_8H_{17}C_6H_4(OCH_2CH_2)_nOH$, $n \approx 9–10$), having molecular weights 364.48 g/mol, 288.38 g/mol and 624 g/mol, respectively, were used for the wetting of respirable sintering dust. Additionally, deionized water was used throughout the experiments.

2.2. FT-IR analysis

Fourier transform infrared spectroscopy (FT-IR, Nicolet 6700, Thermo Fisher Scientific, USA) was used to analyze the chemical groups and bonds on the near-surface region of the sintering dust using potassium bromide method. Spectra were acquired in the range of 4000–500 cm^{-1} with 0.5 cm^{-1} resolution and processed using OMNIC software. The solid samples were prepared for the investigation by mixing with potassium bromide (KBr), then ground and pressed into disks.

2.3. XPS analysis

X-ray photoelectron spectroscopy (XPS) measurement was performed on the respirable sintering dust and samples treated by surfactants by ESCALAB 250Xi (Thermo Fisher Scientific, USA) with Al Kα radiation. The energy spectra were employed to a hybrid fitting of Gauss-Lorentz by XPSPEAK4.1 software, adjusting the binding energy of C1s (284.8 eV) as a reference condition [24].

2.4. Wettability test

Considering the hydrophobicity of the respirable sintering dust, wettability test was employed to determine the content of wettable part in respirable sintering dust by partitioning the sample into unwetted or hydrophobic (water fearing) and wetted or hydrophilic (water loving) fractions in separating funnel after stirring with water [25]. Unless otherwise specified, the wettability