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Preparation of New Surfactant and Study on its Application in Ultra-low Emission of Flue Gas

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ABSTRACT

In this paper, with different types of optimal surfactant monomers and potentiators mixed, the optimum formula of the new surfactant was obtained. The new surfactant with low toxicity, low cost and good dust removal effect was developed by the simulated flue gas experiment and verified the removal efficiency of the new surfactant on the particulate matter in the flue gas. It provided a reference for the industrial application in ultra-low emission of coal smoke. The results showed that the new surfactant could effectively reduce particulate matter in the simulated flue gas, and be the best to the dust particle size less than or equal to 1 micron. The optimum formula was worked out to be: anionic surfactant sodium dodecylbenzene-sulfonate (SDBS) 0.06%, anionic surfactant rapid penetrant T 0.06% and inorganic salt NaCl 1%.

INTRODUCTION

Particulate pollutants have a wide range of influences on urban air quality in China, and it is the first major factor affecting urban air pollution (Zhou et al. 2018). At present, the electrostatic precipitator and bag collector are the main dust removal devices in coal-fired power plants at home and abroad (Zhang et al. 2019, Zhao et al. 2019). However, the efficiency of the traditional electrostatic precipitator for the treatment of tiny particles is still low, and it cannot meet the requirement of ultra-low emissions in the object region. The wet electrostatic precipitator traps the dust particles directly. Through collision interception, adsorption and coagulation with the nozzle spraying, the captured dust would be scoured into the ash bucket and discharged with the flowing water. Surfactants have been applied to dust control all over the world since the 60s of the last century (Guo et al. 2018, Wang et al. 2018, Zhou et al. 2017). The surfactant can not only reduce the surface tension of the water, but also increases the adsorption of the solution. So the coal dust gets fully humid, thereby losing the flowing ability (Zhou et al. 2018, Tang et al. 2016, Yao et al. 2017, Azum et al. 2017). Nevertheless, the effect is not ideal using surfactant monomer for dust control. The application of mixed surfactant, compounded by the optimized surfactant monomers and worked by the synergism effect, is very extensive (Tardy et al. 2017, Zhao & Wang 2017, Zhang et al. 2017, Zhang et al. 2019). The best formula is selected, and the effect is much better than that of monomer (Xi et al. 2017, Hwang et al. 2018). After compounding, the amount of surfactant can be effectively reduced, so can be the cost. And the addition of inorganic salt improves the surface activity of the mixed solution (Ray et al. 2018, Wang et al. 2018). Through the simulation of flue gas test, the removal rate of smoke and dust particles with new surfactant is verified, so the best comprehensive effect program is obtained. We infer that the application of the wet electrostatic precipitator with the new surfactant sprayed to a coal-fired power plant, not only can remove the retained particles in the flue gas, but also the SO_3 and gypsum particles, further the flue gas can be purified (Lee & Valla 2017, Plamper & Richtering 2017, Mazlan et al. 2018).

MATERIALS AND METHODS

Raw materials: Experimental raw materials include: sodium dodecylbenzene-sulfonate (SDBS), sodium silicate, rapid penetrant T, hexadecyl trimethyl ammonium chloride (1631), lauryl dimethyl amine oxide (OA-12), alkyl glycoside (APG), dodecyl dimethyl betaine (BS-12), alkali resistant penetrating agent (JFC), absolute alcohol, sodium chloride, calcium chloride, and anhydrous sodium sulphate.

The preparation of new surfactant: Selecting monomer from many kinds of surfactants, compounding them pairwise

to obtain the mixed solution, adding kinds of soluble inorganic salts as potentiators, choosing the best two solutions with potentiator, halving the ingredients of surfactant and compounding them again, then the best new surfactant is obtained. The surface tension, contact angle and coal dust settling time should be measured with every step.

Smoke simulation experiment: We calculated the quality of coal dust required for the experiment, and then opened the storage tank and poured the coal dust into it. Moreover, the injection tube was inserted into the atomizer nozzle, then the atomizer plug was inserted into the main warehouse body, with pipes and lines of the air compressor and the dust-generating device connected. The power switch was turned on, and the dosing flow rate, time and speed were set. Opening the air compressor, the pressure was adjusted to 0.2 MPa and the flow rate of the mixture and pure gas was adjusted. Then the simulated particles were ready. The surfactant was mixed and poured into the aerosol generating device, and then sprayed into the simulation device of smoke through the pipes and lines connected with it.

With the new surfactant sprayed into the simulated flue gas generator, particles in the flue gas were lignite powder less than 75 microns (μm). Air compressor adjusted to make the dust concentration in the simulated flue gas achieved the requirement of the experiment. The dust concentration was measured by TSI dust meter, and the time needed to reduce the dust concentration from 80 mg/m^3 to 30 mg/m^3 was recorded. The removal efficiency of particulate matter in the flue gas by a new surfactant was analysed.

RESULTS AND DISCUSSION

The Preparation of Mixed Solution

Halving the ingredients of the selected monomer, and compounding the anionic surfactant rapid penetrant T (0.03%) with nonionic surfactant APG (0.10%) and SDBS (0.075%), the wettability of the mixed solution was measured and compared. It can be seen from Fig. 1 that reducing the mass concentration of surfactant makes the surface tension, contact angle and settling time of the mixed solution increased, indicating that the concentration of surfactant will influence the wettability of the mixed solution.

The Preparation of the New Surfactant

Using the previous three ingredients to compound again, and adding the inorganic salt NaCl, 5 groups of the solution were obtained with different concentrations. The surface tension, contact angle and settling time of the solution were measured respectively.

Formula A: Nonionic surfactant APG (0.10%), anionic surfactant rapid penetrant T(0.06%) and inorganic salt NaCl (1%).

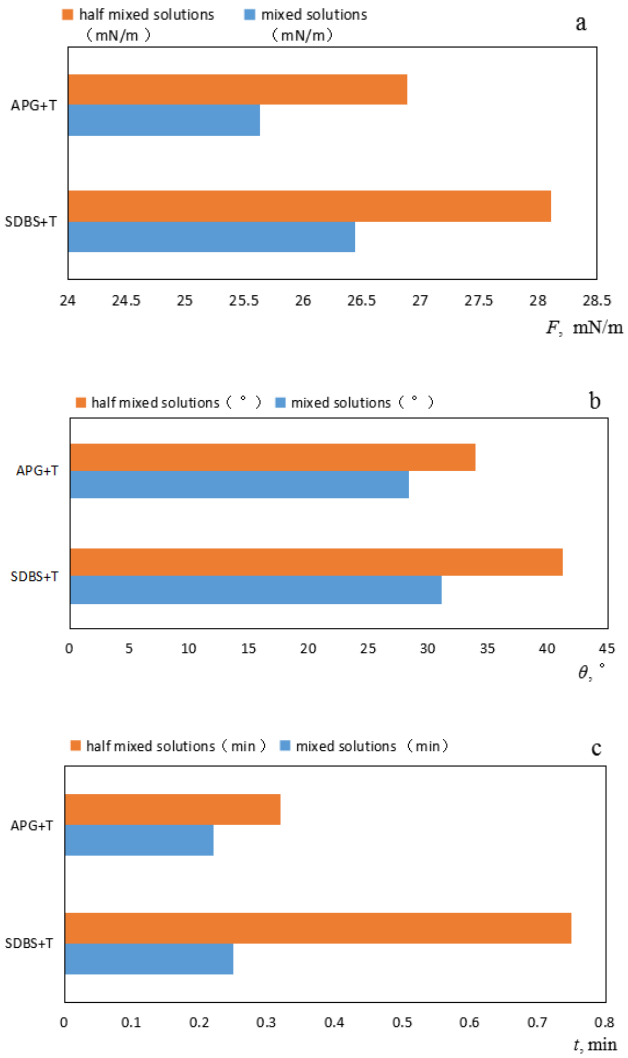

Fig. 1: Surface tension (a), contact angle (b) and settling time (c) at different concentrations of compound solutions.

Formula B: Nonionic surfactant APG (0.08%), anionic surfactant rapid penetrant T(0.06%) and inorganic salt NaCl (1%).

Formula C: Anionic surfactant SDBS (0.08%), anionic surfactant rapid penetrant T(0.06%) and inorganic salt NaCl (1%).

Formula D: Anionic surfactant SDBS (0.08%), anionic surfactant rapid penetrant T(0.04%) and inorganic salt NaCl (1%).

Formula E: Anionic surfactant SDBS (0.06%), anionic surfactant rapid penetrant T(0.06%) and inorganic salt NaCl (1%).

It can be seen from Fig. 2, comparing formula A with B,

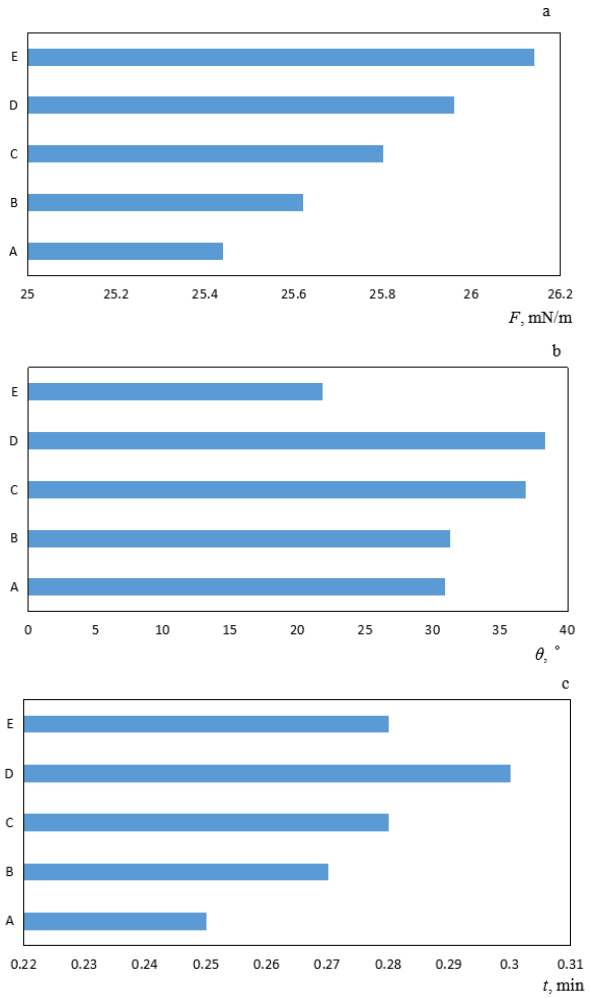

Fig. 2: Surface tension (a), contact angle (b) and settling time (c) of different compound schemes.

when the concentration of nonionic surfactant APG is decreasing, the values of the surface tension, contact angle and settlement test of the mixed solution are increasing. The nonionic surfactant APG has great contribution to improving the wettability of the mixed solution, so the formula A is better. Comparing formula C with D, when the concentration of rapid penetrant T is decreasing, the surface tension, contact angle and settling time of the mixed solution are increasing. Comparing C with E, reducing the concentration of anionic surfactant SDBS, the settling time of the mixed solution remains unchanged, the surface tension increases, but the contact angle decreases. The results show that reducing wettability of anionic surfactant T will weaken the wettability of mixed solution; otherwise, it will enhance the wettability of mixed solution. Therefore, the rapid penetrant T contributes greatly to improve the wettability of the mixed solution. As a whole, formula E is better than the other two.

Study on the Simulation of the New Surfactant

With the preparation of the new surfactant, two kinds of composite formulas with the best wettability were selected. Formula A: APG (0.10%), rapid penetrant T (0.06%) and NaCl (1%). Formula E: SDBS (0.06%), rapid penetrant T (0.06%) and NaCl (1%). From Fig. 3, it is clear that spraying surfactant A or E into the simulation device both can effectively shorten the time needed for the reduction of PM1, PM2.5 and PM10 from 80 mg/m^3 to 30 mg/m^3 in the simulated flue gas. The percentage of settling time of PM1 in flue gas decreases more than 60%, so the two kinds of surfactants on dust particles less than 1 micron in simulated flue gas is good for the effect of dustfall, and E is better. In summary, through the simulation test, it is found that the two new surfactants can effectively improve the dust reduction effect of the particles in flue gas, and can achieve the expected goal. It provides a theoretical basis for the use of surfactant for wet ESP to be sprayed with water or combined with a desulfurization system to spray dust with lime, to achieve the purpose of ultra-low emissions.

The Practical Analysis of New Surfactant

The toxicity of new surfactant: The toxicity of a surfactant mainly refers to the poisonousness of surfactant, because the inorganic salt is non-toxic to the human body. The toxicity of surfactant mainly includes 3 aspects: (1) the toxicity of surfactant, such as acute, subacute and chronic toxicity; (2) mutagenicity, mainly carcinogenicity; (3) effects on reproduction. The toxicity of surfactant usually refers to acute toxicity, generally expressed in a lethal dose of LD_{50}, unit mg/kg. That is the lowest dose required for half of the death of the experimentally injected animal. The smaller the lethal dose, the greater is the toxicity. The cationic surfactant has the highest toxicity in various types, followed by anionic, zwitterion and nonionic. The lethal dose LD_{50} of the three surfactants used in the experiment is given in Table 1. It can be seen from the table that the SDBS has the highest toxicity, and the lethal dose LD_{50} is 1260 mg/kg. Calculated by 50 kg with the body weight, acute poisoning occurs in human beings with a one-time oral dose of 63 g. However, the concentration of the surfactant in SDBS is 0.06%, hence the acute poisoning happens for an oral dose of 105 kg, which is impossible. Moreover, according to the study, the surfactant is not accumulated in the body, but will be decomposed by the body instead, and then excreted. So the new surfactant is non-toxic. Surfactant has certain irritation and sensitization to the skin. The irritation and sensitization are caused by biochemical reactions with the protein, mainly because of the penetration into the skin.

Table 1: Lethal dose LD_{50} of the surfactant monomer.

Surfactant	LD_{50} (1)(mg/kg)
SDBS	1260
Rapid penetrant T	1900
APG	>35000

(1) LD_{50} is defined as the required dose of half of the subjects given is to die caused by chemical.

Table 2: Market prices of new surfactant ingredient.

Reagents	Specification	(Yuan/t)
SDBS	technical grade	3200
Rapid penetrant T	technical grade	9000
APG	technical grade	8500
NaCl	99%	800

The acute toxicity and the skin irritation of different types of surfactant are the cationic, the anionic, the amphoteric and the non-ionic. According to the lethal dose of surfactant, it can be seen that each ingredient of the new surfactant in this experiment has little harm to the human body, and its irritation and sensitization to skin are also very tiny. Therefore, those two new surfactants developed by this experiment are harmless to human body.

The economy of new surfactant: Anionic surfactant (SDBS, rapid penetrant T), nonionic surfactant (APG), and inorganic salt sodium chloride are contained in the new surfactant in this experiment, the market price of these components are given in Table 2. According to the market price, the cost of the main component of the new surfactant is budgeted in the table.

Formula A: APG (0.10%), rapid penetrant T(0.06%) and NaCl (1%). Therefore, 1 kg of APG, 600g of fast penetrant T and 10 kg of NaCl per ton. The cost is 8.5+5.4+8=21.9 YUAN.

Formula E: SDBS (0.06%), rapid penetrant T(0.06%) and NaCl (1%). Therefore, 600 g of SDBS, 600 g of fast penetrant T and 10 kg of NaCl per ton. The cost is 1.92+5.4+8 = 15.32 Yuan.

Comparing the cost of the two new surfactants, formula E is much cheaper than formula A, so the best option is formula E.

CONCLUSION

1. The wettability of most mixed solutions is better than that of the monomer solution. In this experiment, the wettability of nonionic surfactant (APG) and anionic surfactant (rapid penetrant T) is better, followed by the combination of anionic surfactant fast penetrant T and SDBS.

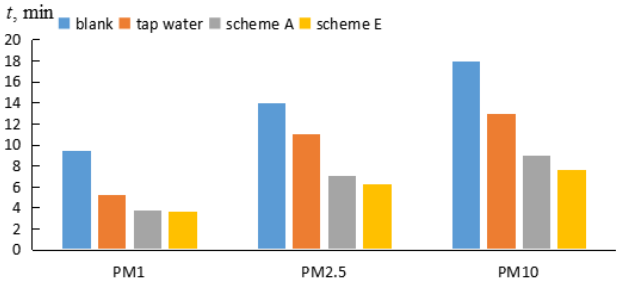

Fig. 3: The time required for the concentration to drop.

2. The wettability of the mixed solution will be decreasing by reducing the concentration of surfactant monomer. In order to reduce the cost, declining the concentration of surfactant, the formula for the best wettability is selected.
3. The two kinds of the surfactant are verified through the simulation of flue gas test, and can effectively reduce different particles in simulated flue gas, in which the particle size less than or equal to 1 micron has the best effect of dustfall.
4. Through the analysis of the toxicity and economy of each component in the new surfactant, it was found that the new surfactant has little toxicity to human body and no irritation to the skin. At the same time, the economic cost calculation shows that the cost of the new surfactant is low and acceptable. Finally, a new surfactant formula with low toxicity, low cost and good wettability was obtained: anionic surfactant SDBS (0.06%), anionic surfactant rapid penetrant T(0.06%) and inorganic salt NaCl (1%).

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