The preparation and performance test of a new type of water-absorbent resin dust suppressant with cation

Yue Sun[1], Xianfeng Zhu[1], Hai Yuan[1], Yuling Qu[1], Junming Huang[1] and Keran Li[1*]

[1] College of Chemistry and Chemical Engineering, Southwest Petroleum University, Chengdu, Sichuan, 610500, China

[*]Corresponding author's email: lkkkkr@163.com

Abstract. In this paper, the cationic monomer was grafted into the dust suppressant molecule innovatively. The dust particles were adsorbed through net capture function, and the dust suppression efficiency was improved by charge interaction for dust particles' electronegative. This experiment adopted the starch, acrylic acid and methacryloyloxyethyl trimethyl ammonium chloride (DMC) as raw materials, with potassium persulfate as initiator and glycerol as the crosslinking agent, synthesizing a new type of water-absorbent resin dust suppressant with cation (later called CNDS). After structure characterization and performance test, the results showed that the cationic monomer were successfully grafted and the CNDS had good functions of keeping moisture, wind-resistant, compressive resistance and anti-erosion. The viscosity of CNDS solution (2%) is 24.7 cP, which can bond and adsorb the dust particles in the air effectively. According to economic cost accounting, spraying CNDS only costs 0.46 yuan per square meter. Hence, there is a great prospect of promotion and application due to its low price.

1. Introduction

For the dust removal problem in the air[1], its treatment methods can be divided into physical and chemical methods. Physical methods include spraying water, windbreak wall for dust prevention and cogongrass covering. The cost of spraying water is high and the overall effect is not ideal[2]. The dust suppression effect of windbreak wall is poor and its long-term exposure to light makes it age easily[3]. Cogongrass covering, namely, is a way that covers the surface of dust - prone substance with tarpaulin. However, its service life is short and the investment cost is high, which will cause resource waste. In conclusion, these traditional dust suppression methods are not only ineffective, but also have obvious disadvantages. Based on this, chemical dust suppressants have developed from nothing to fine. Since the 1920s, chemical dust suppressants have been developed all over the world and used to prevent dust particles from entering the atmosphere. According to the mechanism, chemical dust suppressants can be classified into four types: wet type chemical dust suppressant, sticking type chemical dust suppressant, condensed type chemical dust suppressant and compound type chemical dust suppressant[4-12]. The first type has poor weatherability, short aging and a certain degree of corrosion to the environment. For the second type, its seepage force is weak and it will cause a certain amount of environmental pollution. The third type has good water absorption and retention, however, it corrodes metal. The fourth type can combine the properties of wetting, coagulation and moisture absorption into a whole, and the dust suppression effect is favorable, but its high investment and technology cost restrain the application.

Over the years, the research on polymer dust suppressant has attracted extensive attention from researchers because the preparation cost of polymer materials have become lower and lower. The starch modified natural polymer resin is highly favored for the good hygroscopicity and moisture retention. In the 1990s, a large number of studies were conducted on starch graft copolymerized polymer materials[13]. At present, chemical modified industrial waste and natural materials are regarded as the frontier of research and development of dust suppressants, and the research and development tends to be efficient, environmentally friendly and sustainable[14]. CNDS synthesized in this experiment is biodegradable and the degradation products do not cause secondary pollution. In addition, based on the theory that some dust particles are negative, so they can be adsorbed, collected and precipitated by charge interaction on account of the grafted cationic groups on the CNDS. At the same time, CNDS, which can play a role continuously within the effective period because of its comprehensive action of viscosity, water absorption and water retention capabilities, has great economic and environmental benefits and broad prospect.

2. Experimental

2.1. Materials

Acrylic acid(AA), glycerol, sodium hydroxide, potassium persulfate and methacryloyloxyethyl trimethyl ammonium chloride (DMC) were analytical reagent and all were purchased from Chengdu Chron Chemicals Co., Ltd. Starch was supplied from Hebei Yan Xing Chemical Co., Ltd. All the ingredients were used as received.

2.2. Preparation of CNDS and NCNDS

Proper sodium hydroxide was added to acrylic acid(AA) to form the acrylic acid solution with a neutralization degree of 67%. Put a certain amount of starch and water into a three-mouth flask, and then gelatinized at 80°C under water bath for 30 minutes. After cooling to room temperature, added prepared acrylic acid solution, DMC monomer, initiator potassium persulfate and crosslinking agent glycerol successively, stirred uniformly and reacted at 65°C in nitrogen - protected environment for 3h. The obtained milkiness viscous liquid was CNDS.

Another dust suppressant (later called NCNDS) was synthesized in order to analyze the strength of cation's adsorption in dust suppressant. Its preparation method was consistent with the previous one, but no cationic monomer was added.

2.3. Structure characterization and performance test

Crushed CNDS and dissolved it in deionized water by stirring to prepare a solution with a concentration of 2% for performance test. Meanwhile, NCNDS was treated in the same way.

2.3.1. IR analysis. WQF-520FTIR type infrared spectrometer (from Beijing Rayleigh Analytical Instrument Co., Ltd) was used in this experiment to obtain the infrared spectrum of CNDS, and we prepared the analysis samples by KBr compression method.

2.3.2. Viscosity measurement. The viscosity of CNDS solution (2%) was determined using a Brookfield DV-III viscometer (from Brookfield) at 30±1 ◦C with the way of measuring three times and obtaining the average value.

2.3.3. Test of dust suppression and anti-pressing performance. Spread a layer of soil samples evenly over the ground. The soil samples were sprayed with the same amount of deionized water and CNDS solution (2%). When the soil samples were consolidated under natural conditions, observed whether cracks and dust appeared on their surface. By comparing two kinds of soil samples' morphology, the dust suppression performance was evaluated. On this basis, two kinds of soil samples were crushed by vehicles to simulate the condition of being under pressure on pavement. By observing the morphology of the two soil samples after compression, the anti-pressing performance of CNDS was evaluated.

2.3.4. Water retention capability test. We put 15g same soil samples in two petri dishes. One was sprayed with 10.5g deionized water and the other with 10.5g CNDS solution (2%). Afterwards, put them in oven to evaporate and weighed every 30 minutes to calculate the water retention rate to make the water retention curve at 40 ℃.

2.3.5. Capability of anti-wind erosion test. The 10.5g CNDS solution (2%) was sprayed evenly in a petri dish with the slope of 30 degrees which contained 15g soil sample. When drying, a 1200W blower was used to simulate four-stage wind, conducted anti-Wind erosion simulation experiment for 30 minutes at this wind speed (the distance between the blower and the petri dish was 20cm). After observation, recorded the quality of the soil sample before and after experiment and calculated the loss rate. Under the same condition, the loss rate of soil samples with deionized water and NCNDS solution (2%) was determined. The capability of anti-wind erosion was evaluated by comparing the difference of soil loss among the three.

2.3.6. Capability of anti-erosion test. After the soil samples, which sprayed with the same quality deionized water and CNDS solution (2%), were dried and consolidated, anti-erosion experiment was carried out on the surface of the consolidation layer by simulating natural rainfall with a sprinkler for a period of time. The difference in the morphology of the two soil samples was observed to evaluate the anti-erosion performance of CNDS.

3. Results and discussion

3.1. The analytical results of the infrared spectrum

In the infrared spectrum of AA(figure 1 a), the medium intensity absorbing peak at 1616 cm−1 and 1721cm-1 belong to C=C and C=O(stretching vibration) separately, the medium intensity absorbing peak at 1285cm-1 is relevant to C-O stretching vibration of carboxyl. For the infrared spectrum of DMC (figure 1 c): 1622 cm-1(characteristic absorption peak of telescopic vibration of C=C), 1725cm-1(characteristic absorption peak of telescopic vibration of C=O), 954cm-1(characteristic signal of quaternary ammonium salt). In the infrared spectrum of CNDS (figure 1 d), the characteristic absorption peak of C=C disappeared, indicating that it has reacted; the characteristic absorption peak of C=O appeared at 1731cm-1, the characteristic absorption peak of quaternary ammonium salt appeared at 954cm-1 and deformation vibration absorption peak of $–CH_3$ at 1478 cm-1 indicate the successful grafting of DMC. The absorption peak in 1275 cm-1 should be C-O stretching vibration characteristic peak in carboxyl and the absorption peaks of carboxylate are found in 1404cm-1 and 1583cm-1, which indicate the successful AA grafting. CNDS is highly hydrophilic, and it contains a small amount of binding water, so the wide stretching vibration peak of -OH occurs over 3000 cm-1. In conclusion, DMC and AA are successfully grafted onto the starch, and the synthesized product is the target one.

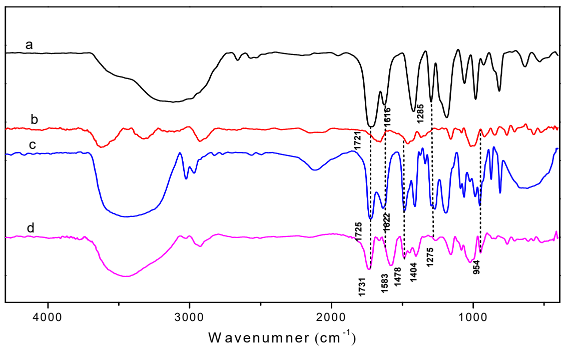

Figure 1. Infrared spectrogram of AA(a), starch(b), DMC(c), CNDS(d).

3.2. Viscosity analysis

The properties of the dust suppressant are determined by its viscosity to some extent. The higher the viscosity is, the greater the ability to bond to dust and the better the curing effect. However, the viscosity should not be too high, which would be detrimental to the stability of product placement[15]. The dust suppressant solution has a good effect at the concentration of 1% to 3%[16], and its viscosity is about 19.10-31.24 cP[17]. In this experiment, the viscosity of CNDS solution with a concentration of 2% was 24.7cP within the above range. Therefore, it has a good effect of dust suppression.

3.3. Dust suppression and anti-pressing performance

It can be seen from figure 2 that the soil sample sprayed with deionized water is almost completely dehydrated, while the soil sample sprayed with CNDS solution has consolidated into a lump and still retains some moisture. This phenomenon shows that CNDS can absorb, moisten, bind soil sample and bring it together. Thus, it can effectively reduce the amount of fine dust and inhibit soil particles into the air, so as to achieve effective dust suppression. From figure 3, after being crushed by a vehicle, the soil sample sprayed with deionized water has become powder, and it can enter the air through the breeze easily. However, the morphology of soil samples sprayed with CNDS solution (2%) remained basically unchanged, and just a small amount of soil samples scattered at the edge. Therefore, it can be qualitatively judged that CNDS has favourable anti-pressing performance.

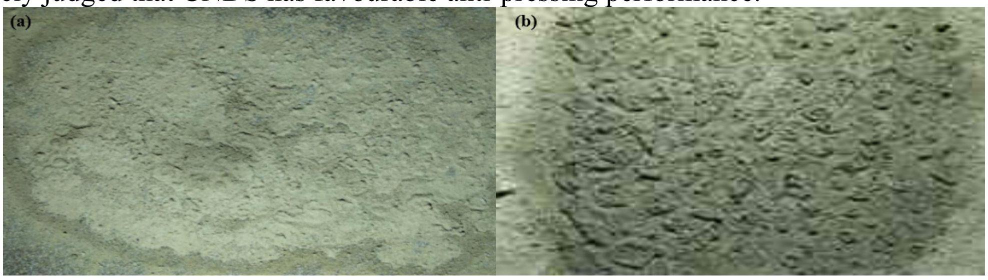

Figure 2. The soil sample sprayed with deionized water (a) and CNDS solution (b).

Figure 3. The soil sample sprayed with deionized water (a) and CNDS solution (b).

3.4. Water retention capability

Figure 4 manifests that the soil sample sprayed with deionized water is almost completely dehydrated after 2.5 hours, while the one sprayed with CNDS solution (2%) still contains 51.94% of water. This is because CNDS molecule has a large number of hydrophilic groups like hydroxyl and carboxyl groups which can interact strongly with water molecules and significantly reduce the evaporation rate of water in soil sample. When the air humidity increases, CNDS can absorb water again, so that it can still maintain good water retention at high temperature.

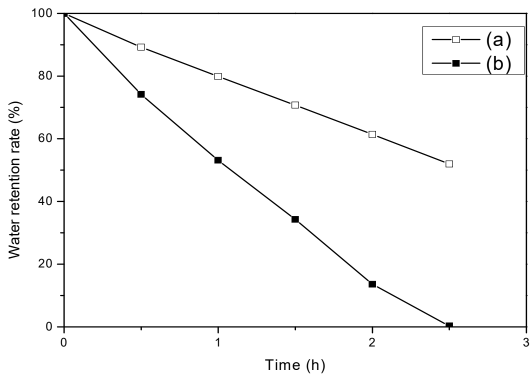

Figure 4. Characterization result of water retention capability. The soil sample sprayed with deionized water (b) and CNDS solution (a).

3.5. Capability of anti-wind erosion

After 30 minutes of anti-wind erosion test, the morphological characteristics of the three soil samples are shown in figure 5. The surface of soil sample sprayed with deionized water is blown away, and its loss rate of soil is 15.24%. Some cracks and fine soil powder appear on the surface of the soil sample sprayed with NCNDS solution, and its loss rate of soil is 2.90%. The surface of soil sample sprayed with CNDS solution is still massive, and its loss rate of soil is just 0.56%. As CNDS and NCNDS solution can wet, bond, firmly absorb soil sample and make it into clumps and effectively resist wind erosion and prevent the consolidation particles from entering the air to become dust again, both of them have lower soil loss rate than soil sample sprayed with deionized water. Comparing the difference of soil loss between CNDS and NCNDS, it can be seen that the interaction of charge can effectively enhance the adsorption performance and improve the dust suppression efficiency.

Figure 5. The soil sample sprayed with CNDS solution (a), NCNDS solution(b) and deionized water (c).

3.6. Capability of anti-erosion

After a period of spraying by the sprinkler, the morphological characteristics of the two soil samples are shown in figure 6. The soil sample sprayed with deionized water is broken up and muddy, so it can be speculated that it is easy to enter the air and become dust again when dry. Nevertheless, the appearance of soil sample sprayed with CNDS solution (2%) remains basically unchanged after scouring and it still accumulates into clumps. The reason for the better anti-erosion performance is that CNDS has certain viscosity and there is a binding force between molecular chains.

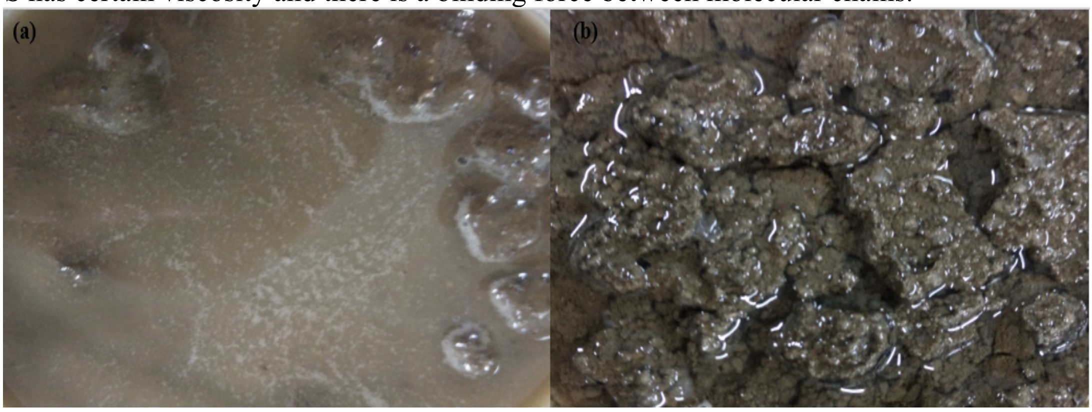

Figure 6. The soil sample sprayed with deionized water (a) and CNDS solution(b).

3.7. Application and advantages of CNDS

CNDS is mainly applied to the treatment of road dust, and there are some advantages about it. First, the production process is relatively simple as one step synthesis is adopted. Second, starting materials are cheap and easy to get. After cost accounting, spraying CNDS only costs 0.46 yuan per square meter, which is far lower than the cost of "SY" dust suppressant synthesized by Leibo Zhang[18] and the dust suppressant material cost of 0.8 yuan per square meter required by the national "863" bidding project[19]. Third, compared with traditional sprinklers, CNDS is easier to adhere to dust particles and gather them to sink down. Fourth, CNDS has good water retention and absorption capacity. Due to the high weight and humidity, the dust particles adsorbed by the CNDS are not easy to enter the air. At the same time, because CNDS can absorb water repeatedly, it also reduces the frequency of spraying, which has great economic benefits. Fifth, CNDS is biodegradable and the degradation products will not cause secondary pollution, which has good environmental benefits. The above advantages indicate CNDS with high comprehensive benefits. Besides dust prevention of urban construction roads, it can also be widely used in mining, transportation, loading, unloading and stacking of coal[20] and minerals, as well as in fields and places that are prone to dust production, such as the open yard.

4. Conclusions

This paper takes the starch, AA and DMC as raw materials, potassium persulfate as initiator and glycerol as the crosslinking agent, synthesizing a new type of water-absorbent resin dust suppressant with cation (CNDS) successfully. Its specific properties are as follows. It contains cationic groups, which can enhance the adsorption performance through charge interaction, and with combined action of wetting, net catching and cementation, the dust can be accumulated into a lump and settled. Additionally, it can effectively suppress the dust and prevent the sedimentation particles from re-entering the air to become secondary dust for its preferable capability of anti-Wind erosion and anti-erosion. Moreover, CNDS has good anti-pressing performance for that its morphology remained basically unchanged after being crushed by the vehicle. It has a good water retention performance after 2.5 hours at 40℃. Furthermore, after dehydration, CNDS can absorb water again when the relative humidity in the air goes up, and this is because there are a large number of hydrophilic groups in its molecular structure.

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