Preparation and homogeneity of polymer mud of underground diaphragm wall

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Abstract. The preparation of homogeneous polymer mud has an important role in the underground diaphragm wall engineering. A homogeneous polymer mud of underground diaphragm wall was synthesized by a simple compounding method in this work. The prepared samples analyzed by infrared spectroscopy. The effects of different film-forming auxiliaries, thickening components and pH on the homogeneity of the diaphragm wall were studied through the measurement of viscosity and specific gravity. The results showed that the prepared polymer mud of underground diaphragm wall had the best homogeneity and stable viscosity in the following conditions: in the pH range of 8-10, the addition of bentonite as a filming auxiliary with 5 kg of puffing agent per ton, and the dosage of vegetable gum was about 10-20 kg in every 100 m³ of mud. The possible reasons of affected homogeneity were suggested.

Keywords: polymer mud, homogeneity, stability, underground diaphragm wall.

1. Introduction

The construction of underground diaphragm wall is convenient and quick, the investment is relatively small, and it has good economic and time benefits [1]. At present, countries are vigorously promoting the construction of infrastructure such as railways, subways, highways, and water conservancy [2-4]. The construction of deep foundation pits, basements, and subway stations of high-rise buildings requires the use of envelope structures. Because of a lot of technical advantages such as low environmental impact and high construction quality, underground diaphragm wall is more widely used in infrastructure construction [5-7]. In the construction of underground diaphragm wall, the formation of trenches with mud retaining walls has become the most important form of groove formation. The quality of mud is the key to ensure the smooth construction of underground diaphragm wall and the quality of wall construction. It is of great significance to study the mud in the trench construction [8]. On the one hand, it supports the retaining wall to prevent collapse; on the other hand, it suspends mud and sand to reduce sediment [9]. When the trench is formed, the soil in the trench is excavated, and the groundwater outside the trench will infiltrate inward. Without the support of the mud wall, the trench wall will be difficult to maintain stability. The mud and sand generated during the formation of the trough can be suspended in the mud to avoid sinking directly to the bottom, causing the sediment to be too thick [10-12].
The traditional mud of underground diaphragm wall is mainly fresh mud and recycled mud. The recycled mud has a large amount of soil, causing a large amount of sediment in the mud pool. The mud pool does not have a sand removal capability; storage space of a mud pool was reduced. If the sedimentation amount of the underground diaphragm wall is large, it will cause the concrete to be difficult to inject, and increase the cost of the concrete [13-14]. As a new material, polymer mud is gradually widely used due to its economic and environmental protection, less deployment time, and high reuse rate of mud. In order to make the mud play a better role in protecting the wall, many researchers carry out secondary processing or modification of the polymer mud to enhance its stability [15-16]. Xie et al. [17-18] controlled the fluid rheological properties of drilling fluids by using a combination of a suitable amount of thermosensitive copolymers and clay particles, thereby enabling the mud to perform better. Li et al. [19] added a surfactant to the polymer mud to enhance the compressive strength and fluidity of the mud. Liu et al. [20] used alkali-activated coal ash as an alternative cementing material to make the mud environmentally friendly without compromising quality. K. Ben et al. [21-23] improve the properties of bentonite and thus enhance the stability of the mud. However, there is currently no related research on the homogeneity of polymer mud. If the homogeneity of polymer mud can be improved in a way, the mud can be kept stable for a long time, so that it can better play the role of polymer mud to protect walls and suspended sediment. It is of great significance to research and modify the homogeneity of polymer mud.

This paper uses a simple method to synthesize a kind of underground diaphragm wall mud with good homogeneity. It is to prepare a polymer mud with good homogeneity, difficulty in layering and stable viscosity by controlling the types and amounts of film-forming auxiliaries and tackifier in the mud, finding out the optimal pH range. Good homogeneity is the basis for the preparation of high-performance polymer mud, and it is of great significance to improve the overall performance of the mud.

2. Experiment

2.1. raw materials
Bentonite, silica fume and calcium carbonate were obtained from Anji Yuhong Clay Chemical Co., Ltd.; Cellulose and vegetable gum were obtained from Tianjin Jinda Zhentong Environmental Protection Technology Co., Ltd.; all drugs can be used without further purification.

2.2. Mud preparation method
Take 2L tap water according to different ratios, pour into a four-necked flask, start the stirring device, control the rotation speed of 400-450r/min, add the soda ash to adjust the pH value of the solution to the four-necked flask, and then add the film-forming powder additive. Stir for 5 min, and finally add the thickening component, the fluid loss component and other additives in one time, and continue to stir for 20 minutes to complete the preparation of the underground diaphragm wall mud.

2.3. Mud homogeneity test method
At the end of the preparation of the mud, the performance test of viscosity and specific gravity is carried out immediately. The viscosity of the mud was tested by using a mud viscosity tester (Model ANY-1, Shangyu Cree Instrument Factory). The mud specific gravity was measured by using a mud pycnometer (NB-1 type, Shangyu Kerui Instrument Factory). After the test was completed, the excess mud was poured into a 2L measuring cylinder, and a static test was carried out to observe the muddy water layer of the mud after standing for 1 day, and the viscosity and specific gravity indexes of the upper mud and the lower mud were respectively taken. The infrared spectrometer was used to study the properties of the polymer functional groups of the dried mud in a scan range of 4000 to 500 cm⁻¹.
3. Results and discussion

3.1. Effect of film-forming auxiliaries on the homogeneity

Bentonite, silica fume and calcium carbonate were used as alternative raw materials for mud film-forming auxiliaries. The effect of single-doping auxiliary on the homogeneity of underground diaphragm wall mud was studied. The viscose component is medium-viscosity cellulose (currently, the commonly used medium-viscosity cellulose is used as the main thickening component of the underground diaphragm wall mud, and its dosage is 100kg/100m³ mud). After standing for 1d, the viscosity, specific gravity and stratification of the mud are measured.

Table 1. The homogeneity of the underground diaphragm wall slurry with different film-forming auxiliaries for 1d

| Serial number | Material usage(kg/100m³) | Viscosity(s) | specific gravity | homogeneity |
|---------------|--------------------------|--------------|-----------------|-------------|
|               | Filming aid | Cellulose | Soda ash | New pulp | Stand still 1d | New pulp | Stand still 1d |
| YZP-1         | 4000       |           |          | 17.61     | 20.5        | 22.7     | 1.03  | 1.03  | 1.03  | Unlayered |
| YZP-2         | 8000       |           |          | 19.1      | 30.2        | 32.3     | 1.06  | 1.06  | 1.06  | Unlayered |
| YZS-1         | 4000       | 100       |          | 16.1      | 16.0        | -        | 1.03  | 1.01  | 1.08  | Layered |
| YZS-2         | 8000       | 120       |          | 16.4      | 16.1        | -        | 1.05  | 1.01  | 1.14  | Layered |
| YZC-1         | 4000       |           |          | 16.7      | 16.3        | -        | 1.02  | 1.00  | 1.10  | Rapid layered |
| YZC-2         | 8000       |           |          | 16.6      | 16.1        | -        | 1.03  | 1.00  | 1.18  | Rapid layered |

Remarks: YZP stands for bentonite; YZS stands for silica fume; YZC stands for ultrafine calcium carbonate.

![Fig. 1 a](image1.png) ![Fig. 1 b](image2.png)

Table 1 and Fig.1 show that when bentonite is used as a film-forming auxiliary, when the dosage is 4000kg and 8000kg, no obvious stratification phenomenon is observed when the mud is allowed to stand for 1d. The proportion of the upper and lower layers of the mud is the same as the specific gravity of the fresh mud. It indicates that the solid phase film-forming particles are stably suspended in the mud system, and there is no obvious agglomeration lower layer, and the mud system is stable.

This is because bentonite has the smallest average particle size and is easier to suspend in the mud system. Secondly, bentonite has puffing properties in an alkaline environment. After chemical and physical combination with water molecules, it first exhibits hydrophilic properties and increases particle swelling. The formation of sol particles results in a decrease in the density of the particles, which helps them to be stably suspended in the mud system. Silica fume and ultra-fine calcium carbonate are used as forming auxiliaries. When the dosage is 4000kg and 8000kg, the mud will show stratification after standing for 1d. The upper and lower layers of mud have a great difference in specific gravity, and the
upper layer has a specific gravity of 1.00~1.01. Close to pure water, and the proportion of the lower layer is more than 50% higher than that of the new mud, indicating that the silica fume and ultra-fine calcium carbonate particles can’t be suspended in the mud system stably, and it is easy to agglomerate and sink. Because silica fume and calcium carbonate have some nanoparticles, they are difficult to disperse completely due to the dispersion process, so it does not have the stable suspension advantage of nanoparticles. Therefore, under the current technical conditions, it is not suitable as a film-forming auxiliary agent for the underground diaphragm wall mud.

However, the test results show that although bentonite has stable suspension characteristics, the viscosity of the bentonite particles changes, the viscosity of the bentonite particles changes, resulting in a large change in viscosity of the system after standing for 1 day, as shown in Fig. 2, when bentonite is used as a filming auxiliary, after standing for 1 d, the viscosity of the system shows a significant change, especially with the increase of the amount of bentonite, the viscosity change is especially obvious. When the dosage is 12000kg, the viscosity of the new mud is only 22s, while the viscosity of the system reaches 43s after standing for 1d, and the viscosity increases by nearly 100 %, the mud basically loses its flow characteristics. In view of the shortcomings of the above bentonite system, in this paper, by changing the expansion characteristics of bentonite, it is preferred to use suitable bentonite as a filming auxiliary for the underground diaphragm wall mud.

![Fig. 2 Viscosity change after bentonite mud standing for 1d](image)

**Table 2. Uniformity of underground diaphragm wall mud with different puffing characteristics**

| Serial number | Material usage (kg/100m³) | Viscosity (s) | specific gravity | homogeneity |
|---------------|---------------------------|---------------|-----------------|-------------|
|               | FILMING AID | | | | |
|               | Cellulose | Soda ash | New pulp | Stand still 1d | New pulp | Stand still 1d |
| YZP1-1        | 4000 | 100 | 16.5 | 16.1 | 17.7 | 1.03 | 1.01 | 1.06 | Layered |
| YZP1-2        | 8000 | 120 | 17.6 | 17.7 | 18.6 | 1.06 | 1.02 | 1.13 | Layered |
| YZP1-3        | 1200 | 150 | 18.2 | 18.8 | 20.6 | 1.09 | 1.03 | 1.15 | Layered |
| YZP2-1        | 4000 | 100 | 16.6 | 16.1 | 18.5 | 1.03 | 1.03 | 1.03 | Layered |
| YZP2-2        | 8000 | 120 | 17.7 | 17.4 | 20.1 | 1.06 | 1.04 | 1.08 | Layered |
| YZP2-3        | 1200 | 150 | 19.0 | 21.1 | 21.0 | 1.09 | 1.09 | 1.09 | Unlayered |
| YZP3-1        | 4000 | 100 | 16.6 | 18.2 | 18.5 | 1.03 | 1.05 | 1.03 | Unlayered |
| YZP3-2        | 8000 | 120 | 18.1 | 20.2 | 20.1 | 1.06 | 1.06 | 1.07 | Unlayered |
| YZP3-3        | 1200 | 150 | 20.2 | 22.6 | 23.0 | 1.09 | 1.09 | 1.09 | Unlayered |
| YZP4-1        | 4000 | 100 | 16.7 | 20.8 | 22.6 | 1.03 | 1.03 | 1.03 | Unlayered |
| YZP4-2        | 8000 | 120 | 19.2 | 30.1 | 32.1 | 1.06 | 1.06 | 1.07 | Unlayered |
| YZP4-3        | 1200 | 150 | 22.7 | 42.1 | 43.0 | 1.09 | 1.09 | 1.09 | Unlayered |

Remarks: YZP1 stands for calcium-based bentonite; YZP2 stands for sodium-based bentonite without puffing agent; YZP3 stands for sodium-based bentonite plus 5kg puffing agent; YZP4 stands for sodium-based bentonite plus 10kg puffing agent.
The expansion characteristics of bentonite are mainly affected by the amount of sodium and puffing agent. Generally, the swelling index of sodium-based bentonite is higher than that of calcium-based bentonite. The swelling index of bentonite increases with the puffing agent. Table 1 shows that after the mud is allowed to stand for 1 d, the calcium-based bentonite and the sodium-based bentonite without the expansion agent are stratified, and when 5 kg and 10 kg of the puffing agent are added per ton of sodium-based bentonite, the mud can’t be stratified and keep it steady.

As shown in Fig. 3, when the amount of the puffing agent is 5kg and 10kg, the viscosity change trend of the mud is different after standing for 1d. When the amount of the expanding agent per ton of sodium-based bentonite is 5kg, the mud is allowed to stand for 1d, and the viscosity is increased. Less than 15%, and when the amount of the expanding agent is 10kg, the viscosity of the mud increases obviously after standing for 1d, and with the increase of the amount of bentonite, the viscosity of the mud increases more obviously. According to engineering experience, when the mud viscosity reaches 40s, it basically loses fluidity and the wall protection effect is poor. Therefore, in order to meet the needs of engineering applications, the film-forming auxiliary should be selected from sodium bentonite with 5 kg of puffing agent per ton. The underground diaphragm wall mud prepared by the method has good homogeneity and stable viscosity.

3.2. Effect of tackifier on the homogeneity
Cellulose and vegetable gum are selected as the alternative materials of tackifier for ground wall mud. The change of mud homogeneity with the amount of tackifier was studied. The filming auxiliary was sodium-based bentonite with 5 kg of puffing agent added per ton. The amount of bentonite in the 100m³ mud is fixed at 8000kg. As shown in Table 3.

| Serial number | Material usage(kg/100m³) | Viscosity(s) | specific gravity | homogeneity |
|---------------|--------------------------|--------------|------------------|-------------|
|               | Tackifier | Bentonite | Soda ash | New pulp | Stand still 1d | New pulp | Stand still 1d | Upper | Lower | Upper | Lower |             |
| YZ-CML-1      | 5         |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-CML-2      | 10        |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-CML-3      | 20        |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-CMM-1      | 5         |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-CMM-2      | 10        |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-CMM-3      | 20        |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-HYL-1      | 5         |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-HYL-2      | 10        |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-HYL-3      | 20        |           |         | 20.1    | 22.2    | 22.8    | 1.06    | 1.05    | 1.06    | Unlayered |
| YZ-HYM-1      | 5         |           |         | -       | -       | -       | -       | -       | -       | Layered   |
| YZ-HYM-2      | 10        |           |         | 18.5    | 19.1    | 19.9    | 1.06    | 1.06    | 1.06    | Unlayered |
| YZ-HYM-3      | 20        |           |         | 20.1    | 21.6    | 21.5    | 1.06    | 1.06    | 1.06    | Unlayered |

Fig. 3 YZP3 and YPZ4 viscosity change after mud standing for 1d
Remarks: YZ-CML stands for low-viscosity cellulose, YZ-CMM stands for medium-viscosity cellulose, YZ-HYL stands for low-viscosity vegetable gum, YZ-HYM stands for medium-viscosity vegetable gum.

It is concluded from Table 3 that low-viscosity and medium-viscosity cellulose are used as tackifiers. When the amount of tackifier is low, the underground diaphragm wall mud will show stratification after standing for 1 d, indicating that the mud homogeneity is poor at this time. The medium-viscosity vegetable gum is used as the viscous component of the underground diaphragm wall mud, and when the dosage reaches 10kg, the mud can be kept homogeneous and stable, and the viscosity of the mud does not increase significantly after standing for 1 d; However, the low-viscosity vegetable gum needs to be mixed to 20kg, in order to maintain the uniformity and stability of the mud. The economical and practical effects are selected as the material selection criteria, and the medium-viscosity vegetable gum is selected as the main viscosity-increasing component of the underground diaphragm wall mud.

The reason why vegetable gum has a better property of improving mud homogeneity is that it has the property of low concentration and high viscosity and has thixotropic property. The aqueous solution of the vegetable gum has high viscosity under static or low shearing action. Under the action of shearing, the viscosity decreases sharply, but the molecular structure does not change. When the shearing force is removed, the original viscosity is immediately restored. The suspension and emulsifying properties of the vegetable gum have a good suspension effect on the insoluble solids. Plant colloidal sol molecules can form a fragile colloidal network structure, showing a strong suspension ability; the vegetable gum solution is very stable to acid and alkali, and its viscosity is not affected at a pH between 5 and 10.

3.3. Effect of pH value on the homogeneity
In the application process of the underground diaphragm wall mud, in order to achieve the purpose of removing Ca$^{2+}$ and Mg$^{2+}$ ions in water, promoting the expansion of bentonite and reducing the corrosion of the drill, the pH of the mud is usually controlled to be alkaline. In this section, the effect of pH change on mud homogeneity is discussed by changing the amount of soda ash.

| Serial number | Material usage(kg/100m$^3$) | pH | Viscosity(s) | specific gravity | homogeneity |
|---------------|-------------------------------|----|--------------|------------------|-------------|
|               | Soda ash | Bentonite | Tackifier | New pulp | Stand still 1d | New pulp | Stand still 1d | Upper | Lower |
| YZ-PH-1       | 0       |           |           | 6.7     | 17.5 | 17.3 | 17.8 | 1.06 | 1.04 | 1.09 | Layered |
| YZ-PH-2       | 50      |           |           | 7.5     | 18.5 | 19.1 | 19.2 | 1.06 | 1.04 | 1.08 | Layered |
| YZ-PH-3       | 70      |           |           | 8.1     | 19.0 | 20.0 | 20.1 | 1.06 | 1.06 | 1.06 | Unlayered |
| YZ-PH-4       | 100     | 8000      | 20        | 9.0     | 20.1 | 22.1 | 22.4 | 1.06 | 1.06 | 1.06 | Unlayered |
| YZ-PH-5       | 150     |           |           | 10.1    | 21.4 | 24.4 | 24.2 | 1.06 | 1.06 | 1.06 | Unlayered |
| YZ-PH-6       | 200     |           |           | 11.6    | 23.5 | 29.5 | 30.1 | 1.06 | 1.06 | 1.06 | Unlayered |
| YZ-PH-7       | 300     |           |           | 13.1    | 23.4 | 33.2 | 34.1 | 1.06 | 1.06 | 1.06 | Unlayered |

Fig. 4 Effect of pH change on mud viscosity
Table 4 shows that when the pH value of the mud is lower than 8.0, the mud homogeneity is poor, and the stratification phenomenon appears after standing for 1 day, which is not conducive to the expansion of bentonite does not eliminate the Ca^{2+} and Mg^{2+} ions in the solution. When the pH value is greater than 10.5, the mud is left for 1d without stratification, but the expansion of bentonite is intensified, leading to an increase in the amount of colloids in the mud, or even a bridge. The free water in the mud system decreases accordingly, resulting in an excessive rise in mud viscosity, which will result in the loss of mud fluidity and wall protection effect. During engineering construction, mud viscosity should be as stable as possible. When the pH value of mud is 8 ~ 10, mud shows the dual characteristics of uniform quality and stable viscosity.

As shown in Fig. 4, a pH less than 8 is a hierarchical zone. The pH higher than 8 and lower than 10.5 is the homogeneous zone corresponding to soda ash dosage of about 70 ~ 150kg in 100m³ mud, and pH higher than 10.5 is the viscosity elevation too high zone. Therefore, when the pH value is between 8 and 10, it is most suitable. Fig. 5 is a graph showing the homogeneity of the pH different muds after standing for 1 d. When pH is equal to 6.7, it is clearly stratified after standing for 1d, which also proves the above statement.

3.4. Infrared measurement
As can be seen from Fig.6, the infrared spectrum characteristics of polymer mud have a very obvious absorption band in the high frequency region at 3616cm⁻¹, which is caused by the stretching vibration of Al-O-H. There is also an absorption peak at 1005cm⁻¹ in the intermediate frequency region, which is caused by the anti-symmetric stretching vibration of Si-O-Si. These two peaks are characteristic of bentonite, which indicates that bentonite is an important component of polymer mud. However, the most important reason for high viscosity and low specific gravity of polymer mud is that the corresponding proportion of vegetable gum is added on this basis. The absorption peak at 1739 cm⁻¹ is C-O stretching vibration, and the stretching vibration of methylene is 1397 cm⁻¹, which indicates that the polymer mud contains galactomannan, which is the main component of vegetable gum. The suspension and emulsification characteristics of vegetable gum have a good suspension effect on insoluble solids. The sol molecules of vegetable gum can form a network structure and show strong suspension ability. Therefore, the final polymer mud has a high homogeneity.
3.5. Mechanism of polymer mud action
Polymer mud is a kind of clear cement mud with high molecular polymer as the main component. It is a long-chain compound formed by linking and polymerizing many monomers and low-molecular compounds. Most of them are polarity and the polymer molecules have a large number of negative charges. The group adsorbs positively charged soil particles in the solution, making the mud difficult to delaminate and maintaining good homogeneity, as shown in Figure 7.a. When the polymer mud is in contact with the groove wall of the underground diaphragm wall, the polymer is adsorbed to the clay particles in the groove wall by hydrogen bonding or electrostatic attraction. Because the polymer generally has a high molecular weight and has a large linear expansion capacity, then it can not only adsorb on one clay particle but also further connect to adjacent clay particles, and connect or bridge multiple clay particles together, as shown in Figure 7.b. This surface adsorption and connection effect comprehensively increases the stability to the surrounding soil layer, prevents the dispersion of the wall soil layer, greatly reduces the sedimentation of the mud, and maintains good homogeneity, thereby ensuring the quality of the underground diaphragm wall.

4. Conclusion
In this paper, a kind of polymer mud with high homogeneity and stable viscosity is prepared in a simple way. Experiments have shown that in the pH range of 8-10, the bentonite which is sodiumized and added with 5 kg of puffing agent per ton is a film-forming auxiliary, and the amount of vegetable gum per 100 m³ of mud is about 10-20 kg, the polymer mud of underground diaphragm has the best homogeneity and stable viscosity.

![Fig.7 Mechanism of polymer mud action](image)

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