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Research Progress on Solid-Liquid Separation Technology for Core Drilling Flushing Fluid

Yunzhu Wang[1,2,a,*], Xin Yu[1,2], Hao Wu[1,2], Jing Zhou[3], Yingcai Tian[1,2]

[1]The Second Bureau of Geological Exploration, China National Administration of Coal Geology, Beijing, China
[2]Resource Exploration Drilling Technology and Equipment Innovation Base, Geological Society of China, Beijing, China
[3]China National Administration of Coal Geology, Beijing, China
[a]laowangaust@gmail.com
[*]Corresponding author

Abstract: *Core drilling is a primary method for mineral resource exploration, with flushing fluid serving as the "lifeblood" of drilling operations. The performance of the fluid directly influences both drilling efficiency and core quality. This article systematically reviews the advancements in solid-liquid separation technology pertinent to core flushing fluids, analyzing the principles, advantages, and limitations associated with various technologies. Furthermore, it addresses current technical challenges and proposes future directions for solid-liquid separation technology development, aiming to provide valuable insights for scientific research and engineering practices in related fields.*

Keywords: *Core Drilling; Flushing Fluid; Solid-Liquid Separation; Technological Progress*

1. Introduction

Core drilling is a primary method for resource exploration, and drilling fluid serves as the "lifeblood" of drilling operations, with its performance directly impacting drilling efficiency and core quality[1-2]. As the demand for deep resource exploration and drilling in complex geological formations grows, the accumulation of solid particles in flushing fluid has become an increasingly prominent issue. Excessively high solid content can lead to reduced drilling speed, accelerated drill bit wear, and instability of the wellbore wall[3-4]. Additionally, flushing fluid serves as a critical medium in the drilling process, performing essential functions such as cooling the drill bit, transporting cuttings, balancing formation pressure, and stabilizing the wellbore wall[5-6]. However, the large volume of waste slurry generated after drilling, if discharged without proper treatment, not only wastes water resources but may also cause environmental pollution. Therefore, flushing fluid solid-liquid separation technology is crucial for ensuring drilling efficiency and reducing emissions. Developing efficient and environmentally friendly solid-liquid separation treatment technologies to achieve the recycling and harmless disposal of flushing fluids is a current research hotspot and challenge in the field of geological exploration.

In recent years, with the deepening of environmental protection efforts and the promotion of green exploration concepts, research on this technology has also gradually intensified both domestically and internationally. Significant progress has been made in solid-liquid separation technology for core flushing fluids. Traditional methods, such as gravitational settling and centrifugal separation, are increasingly being supplemented and replaced by modern technologies like membrane separation and flocculation. Additionally, the development and application of new materials and equipment have further enhanced the efficiency and adaptability of solid-liquid separation. This paper will discuss the research progress of solid-liquid separation treatment technology for core flushing drilling fluids from the perspectives of technical classification and principles, and provide insights into future development trends.

2. Flushing Fluid Characteristics and Separation Difficulties

2.1 Flushing Fluid Composition and Classification

Flushing fluid is a colloidal dispersion composed of a dispersing medium (continuous phase), a dispersed phase, and a chemical treatment agent, and its composition varies depending on the drilling

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process and formation conditions. As shown in Figure 1, flushing fluids are usually classified in the following ways:

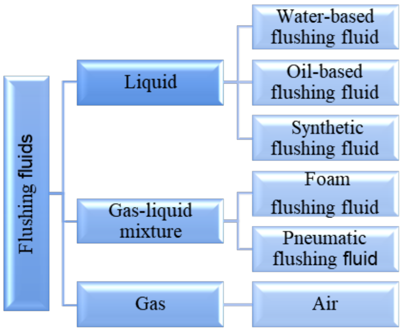

Figure 1: Classification of flushing fluids.

1) According to density, they can be divided into: non-weighted flushing fluids and weighted flushing fluids.

2) According to solid phase content, it can be divided into: no solid phase flushing fluid, low solid phase flushing fluid, and high solid phase flushing fluid.

3) According to temperature resistance, it can be divided into ultra-low temperature flushing fluid, low temperature flushing fluid, and high temperature flushing fluid.

4) According to the degree of bentonite dispersion, they can be divided into: finely dispersed flushing fluids, coarsely dispersed flushing fluids, and non-dispersed flushing fluids.

5) According to phase state and system composition, they can be divided into: water-based flushing fluids, oil-based flushing fluids, synthetic-based flushing fluids, gas-containing circulation media, and gases.

2.2 Difficulties in Flushing Fluid Separation Technology

The efficient separation of core drilling flushing fluid faces serious challenges, with the core difficulties lying in the complexity of the flushing fluid and the harshness of the drilling environment. As shown in Figure 2, this is mainly reflected in the following points:

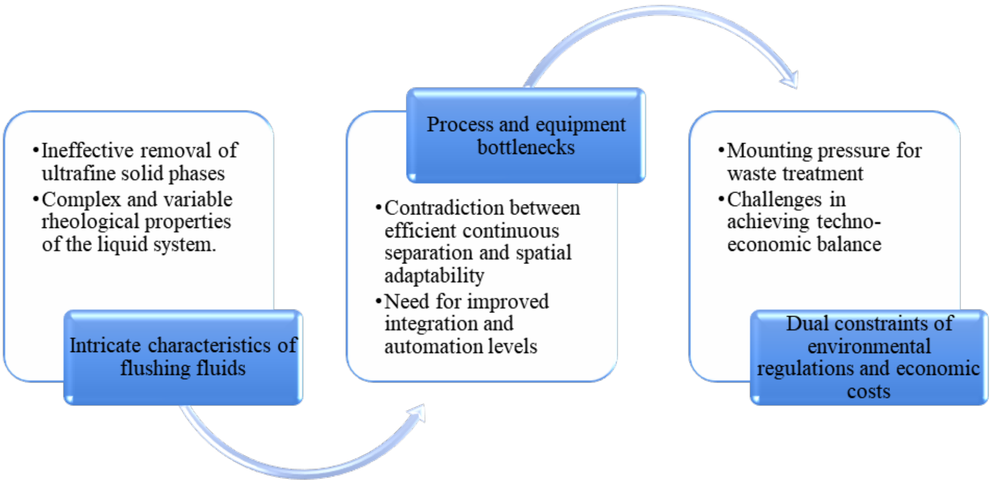

Figure 2: Difficulties in flushing fluid separation technology.

1) The characteristics of flushing fluid are complex. Domestic geological core drilling mainly uses diamond wire core drilling technology, which produces fine rock powder particles. However, the lack of professional solid phase control equipment on site causes the rock powder to be further crushed and dispersed in the flushing fluid in an extremely fine state (particle size <5μm), forming a highly dispersed stable colloidal suspension system. Traditional primary separation methods, such as sedimentation tanks and vibrating screens, are inefficient. The efficient removal of these fine particles requires fine separation equipment such as cyclones or centrifuges, but these require extremely high equipment precision and

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parameter matching (pressure, flow rate) and consume a lot of energy. The remaining fine particles will deteriorate the rheological properties of the flushing fluid and exacerbate drill tool wear.

In order to meet the needs of complex formation drilling, a variety of chemical treatment agents (such as thickening agents and loss reducers) are often added to the flushing fluid. Its viscosity, dynamic shear stress, and static shear stress parameters are significantly affected by factors such as temperature, shear rate, and solid phase content (colloidal particles), making it difficult to control the separation process in a stable manner.

2) Processing technology and equipment bottlenecks are prominent. The drilling process requires continuous circulation and purification of the flushing fluid. Domestic geological drilling sites mostly follow the concept of petroleum drilling solids control technology, and the equipment often has problems such as a large footprint, low integration, and insufficient intelligence. This is particularly prominent in mountainous areas and plateaus. Existing equipment is not sufficiently adaptable to the high solid phase content flushing fluid generated by diamond wire core drilling, and the processing efficiency is difficult to meet requirements.

The development of compact, highly automated integrated separation systems suitable for the characteristics of geological core drilling (small scale, high mobility, and variable working conditions) faces the challenges of difficult technical integration and high development costs. Domestic technology still lags behind international advanced levels in terms of intelligent control, miniaturization design, and deep integration with drilling processes for high-efficiency separation units (especially those addressing extremely fine particles).

3) Dual constraints of environmental policies and economic costs. Increasingly stringent environmental regulations require that separated solid rock cuttings be disposed of in compliance with regulations, and that the liquid phase containing residual chemical treatment agents meet discharge standards or safe reuse requirements, thereby achieving resource utilization of waste. This significantly increases the technical difficulty and overall cost of achieving compliance.

Under the pressure of cost control in drilling projects, developing and applying separation technologies and equipment that can meet efficient separation requirements (removal of fine particles), adapt to harsh environments, comply with environmental protection requirements, and also have good economic viability presents significant challenges.

3. Progress in Research on Flushing Fluid Solid-Liquid Separation Technology

3.1 Traditional Flushing Fluid Solid-Liquid Separation Technology

1) Gravity sedimentation method. Gravity sedimentation is a separation method that utilizes the density difference between suspended particles and liquids to cause the particles to settle naturally under the action of gravity. This method is implemented through a mud settling tank and has the advantages of a simple structure and low cost. It was widely used in early core drilling projects. As shown in Figure 3, the Qinghai Bureau Exploration Branch Company adopted multi-stage liquid supply pumps and fully enclosed circulation pipelines in the Muli Junan project to divert drilling mud from the wellhead to newly installed solid-liquid separation equipment and circulation tank chambers on the surface for sequential separation processing[7]. Solid phase materials were transported via deflector plates to a waste solid phase collection and storage pit, while the liquid was treated for reuse. However, the separation efficiency of the gravity settling method is relatively low, the processing cycle is long, it requires a large footprint, and it is difficult to handle high-concentration, fine-particle suspensions, especially in complex geological formations.

Figure 3: Field test of a 6-6 borehole in the Muli Junan project.

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2) Centrifugal separation. Centrifugal separation utilizes centrifugal force to accelerate particle settling, significantly improving separation efficiency. Common centrifugal equipment includes horizontal screw centrifuges, disc separators, and others. Centrifugal separation offers advantages such as high processing capacity, compact footprint, and high automation levels, making it suitable for separating suspensions of moderate concentration. For example, the KG-300-2J system developed by the Chongqing Research Institute of China Coal Technology & Engineering Group integrates a vibrating screen and a centrifuge unit, and uses a two-stage purification mode to achieve efficient separation, with the solid phase content of the flushing fluid after treatment being less than 0.15%[8]. Its centrifuge adopts a horizontal screw structure and dynamically adjusts the differential speed ratio through frequency conversion control to adapt to different particle sedimentation characteristics. However, centrifugal separation methods have high energy consumption, with the motor power of this centrifuge reaching 18.5 kW, and the equipment maintenance costs are high, with limited separation efficiency. In practical applications, equipment parameters (such as speed and separation factor) must be selected based on formation characteristics (such as particle size and viscosity), processing scale, and environmental standards, and combined with flocculation, membrane separation, and other technologies to form a synergistic process.

3) Plate-and-frame filtration method. Plate-and-frame filter presses achieve solid-liquid separation through high-pressure physical compression, reducing the moisture content of the filter cake to 30%-50%. If membrane filtration technology is used, the moisture content can be further reduced to below 20%. This method offers advantages such as high dewatering efficiency, clear filtrate, and recoverable filter cake, making it particularly suitable for scenarios with strict dewatering requirements, such as the recovery of fine chemical raw materials or the treatment of hazardous waste sludge. As shown in Figure 4, the Jinkaidi Intelligent Variable Cavity Pressing Machine dynamically adapts to material characteristics through its intelligent variable cavity system, enhances separation efficiency with ultra-high-pressure pressing technology, and reduces operational costs via an intelligent maintenance system[9]. It has achieved excellent application results in municipal sludge treatment and mine tailings processing. However, plate-and-frame filter presses have drawbacks such as long processing cycles, large equipment size, and low automation levels, and the filter cloth is prone to blockage, requiring frequent replacement.

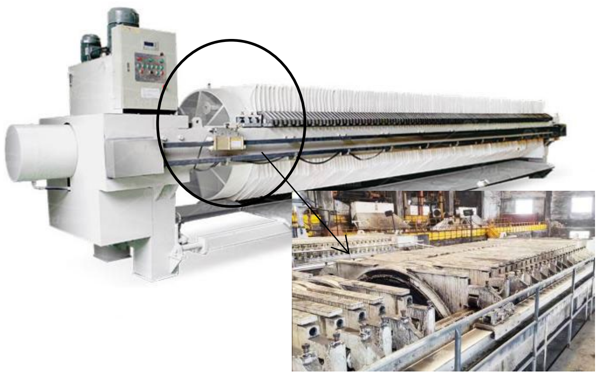

Figure 4 Jinkaidi intelligent variable cavity pressing machine.

3.2 Modern Solid-Liquid Separation Technology

1) Membrane Separation Technology. Membrane separation technology utilizes the selective permeability characteristics of semipermeable membranes to achieve solid-liquid separation and solute concentration. Common membrane separation methods include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. Membrane separation technology offers advantages such as high separation precision, simple operation, and low energy consumption, enabling effective removal of colloids and small organic molecules from rinse solutions. As shown in Figure 5, the graphene-enhanced high-barrier and fast-curing film developed by Academician Xie Heping's team achieves efficient barrier properties against small molecules such as water and hydrocarbons, as well as ions, within rock cores through molecular structure design and synergistic reinforcement by fillers[10]. The preservation, moisture retention, and light retention efficiencies reach 99%, 99%, and 100%, respectively. However, membrane separation technology has problems such as severe membrane contamination, short membrane life, and high cost, and has limited processing capacity for high-concentration suspensions.

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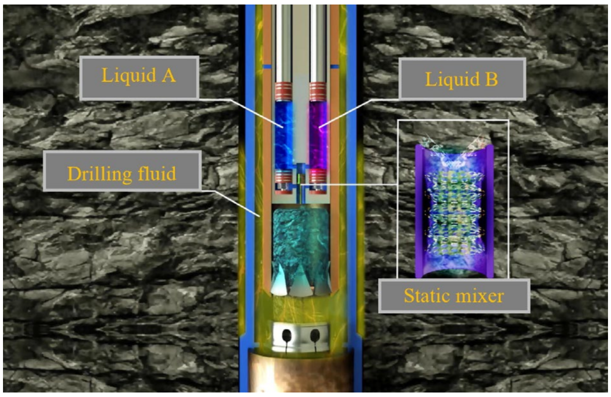

Figure 5 Graphene-enhanced high-barrier and fast-curing film.

2) Flocculation technology. Flocculation technology accelerates sedimentation or filtration by adding flocculants to the flushing fluid to form larger flocs from suspended particles. Commonly used flocculants include inorganic flocculants (such as polyaluminium chloride and ferrous sulfate), organic polymer flocculants (such as polyacrylamide), and biological flocculants. Flocculation technology has the advantages of high treatment efficiency, strong adaptability, and low cost, and can significantly improve the sedimentation performance and dehydration effect of flushing fluid. As shown in Figure 6, the GB-1 high-efficiency gum breaker and SF-100 composite curing agent developed by the Institute of Exploration Technology of the Chinese Academy of Geological Sciences have established a set of harmless treatment technologies and processes suitable for geological drilling waste flushing fluid, and the treated water quality can meet Class V emission standards[11]. However, the selection and dosage of flocculants need to be optimized according to the composition and properties of the flushing fluid; otherwise, it may lead to secondary pollution or poor treatment results.

Figure 6 Disposal of flushing fluid and flocculation of broken glue.

3) Biological treatment technology. Biological treatment technology utilizes the metabolic action of microorganisms to decompose organic pollutants in flushing fluids into harmless substances. Common biological treatment methods include activated sludge, biofilm, and anaerobic digestion. Biological treatment technology has the advantages of being environmentally friendly and having low operating costs, and can achieve harmless treatment and resource utilization of flushing fluids. For example, a method for the treatment of core drilling mud waste liquid involves stepwise treatment of the waste liquid using pretreatment agents and post-treatment agents[12]. The non-ionic polyacrylamide in the pretreatment agent synergistically acts with modified activated carbon particles to encapsulate, adsorb, and flocculate oil residues, heavy metal particles, and large molecular chemicals in the mud waste liquid. The post-treatment agent combines amide-based sludge solidifiers with alkali-treated Artemisia plants to solidify the “turbid liquid,” ultimately forming solid waste with a volume of only 5%-8% of the original drilling mud waste liquid volume. However, biological treatment technology has strict requirements for environmental conditions (such as temperature, pH value, dissolved oxygen), has a long treatment cycle, and has limited effectiveness in removing difficult-to-degrade organic substances.

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4. Future Innovative Development Directions for Core Drilling Fluid Solid-Liquid Separation Technology

Currently, core drilling fluid solid-liquid separation technology has achieved notable progress. However, given the complexities associated with deep formation drilling and increasingly stringent environmental regulations, further advancements are required in the following areas:

1) Researchers should integrate the advantages of gravity settling, centrifugal separation, and flocculation technologies to establish a highly efficient and energy-saving synergistic treatment process, thereby enhancing the treatment efficiency of drilling fluids in complex formations.

2) It is essential to promote the development of intelligent equipment to improve system reliability and adaptability. For instance, manufacturers should develop mobile, modular, and skid-mounted treatment units to accommodate the needs of dispersed drilling sites. Researchers use the Internet of Things and big data technology to build an intelligent solid-liquid separation processing system to realize real-time monitoring of equipment operating parameters, fault warning, and remote control, and improve management efficiency.

3) In the future, researchers will actively explore the waste recycling technology of flushing fluid treatment to maximize the utilization of resources. Develop ways of resource utilization of solid waste according to local conditions, such as for site roadbed, brick making, etc.

4) The industry must adhere to the principle of green exploration by strengthening the research and application of novel, environmentally friendly materials, reducing the reliance on chemical additives, and achieving sustainable development in core drilling. This includes utilizing biomass or mineral-based materials to develop eco-friendly treatment agents, such as biodegradable flocculants derived from starch and cellulose.

5. Conclusions

Core drilling washwater solid-liquid separation treatment technology is crucial for ensuring drilling operation efficiency and reducing emissions pollution. Traditional technical methods such as gravity settling, centrifugal separation, and plate-and-frame filtration primarily rely on physical separation and are still widely applied in engineering projects. However, they suffer from issues such as low efficiency and poor adaptability. Modern technologies like membrane separation and flocculation utilize chemical-mechanical synergistic effects to significantly enhance separation efficiency and environmental performance. The development and application of new materials and intelligent equipment have brought new breakthroughs in solid-liquid separation technology. However, challenges such as adaptability to complex geological formations, treatment of high-concentration suspensions, equipment reliability, and economic viability still require further resolution. In the future, we should strengthen multi-technology synergy, new material research and development, resource recycling, and intelligent management to promote the development of core drilling flushing fluid solid-liquid separation treatment technology in the direction of high efficiency, environmental protection, and intelligence, providing strong support for the green sustainable development of the geological exploration industry.

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