International Journal of Electric Power and Energy Studies
ISSN: 3006-2004 (Print), ISSN: 3006-0826 (Online) | Volume 2, Number 3, Year 2024
DOI: https://doi.org/10.62051/ijepes.v2n3.13
Journal homepage: https://wepub.org/index.php/IJEPES/index

Study on the Mechanism of Algae Bacteria Symbiotic System in Treating Fracturing Flowback Fluid

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ABSTRACT

Fracturing operations in oil and gas wells are one of the main measures to increase production. Fracturing flowback fluid has the characteristics of high viscosity, high COD value, and containing multiple chemical reagents, making it difficult to treat. It has become one of the main pollutants in oil fields. Directly discharging untreated fracturing fluid can cause serious pollution to the environment and soil. Therefore, in-depth research on the treatment methods of fracturing flowback fluid is of great significance for environmental protection and cost reduction in oil and gas fields. This article systematically analyzes the sources, components, pollution characteristics, and treatment status of fracturing flowback fluid. The efficient treatment of fracturing flowback fluid using a microalgae aerobic bacteria mixed culture system was conducted, and the mechanism of algae bacteria symbiotic treatment of oily wastewater and the mechanism of microalgae aerobic bacteria mixed culture purification of fracturing flowback fluid were analyzed in depth.

KEYWORDS

Fracturing Flowback Fluid; Bacteria and Algae Symbiosis; Mechanism of Pollutant Removal.

1. INTRODUCTION

As oil fields enter a period of declining production, major oil fields carry out secondary and tertiary oil recovery in order to increase production and improve recovery efficiency [1-3]. Usually, after water injection and gas injection development, fracturing becomes one of the main measures to increase oil and gas well production [4]. During the fracturing process, fracturing fluid needs to be injected into the formation. In the conventional fracturing construction operation of oil fields in China, the volume of fracturing backflow fluid per well per day for each drilling team is 100-200m^3. The residual fracturing waste liquid discharged from conventional fracturing operations is mainly water-based fracturing fluid, which contains a large amount of guar gum, petroleum, chloride ions, formaldehyde, and various additives. At the same time, the vast majority of wastewater also contains harmful substances such as crude oil and phenols [5,6]. Therefore, the composition of fracturing flowback fluid is complex, with a variety of pollutants, high content, high viscosity, high COD, high stability, and difficult treatment. If a large amount of fracturing backflow fluid is discharged or reinjected into the formation without reasonable and effective treatment, it will cause serious pollution to soil, vegetation, and water bodies. If heavy metal ions in the wastewater enter the food chain, it will seriously endanger human health. Therefore, it is extremely important to reduce the various pollution indicators of fracturing flowback fluid to a certain extent in order to meet the discharge standards [7,8]. At present, most of the commonly used fracturing flowback fluid treatment methods are physical or chemical treatment methods, and the sewage indicators treated by these methods often do not meet the national sewage discharge standards. Chemical treatment technology can significantly improve the water quality and biodegradability of the effluent, but it also exposes some problems during the treatment process, such as the risk of secondary pollution [9]. Chemical methods require a large amount of treatment agents and inject a large of soluble ions into wastewater. If directly discharged, it can easily cause soil and water pollution; Once the treated fracturing wastewater is reinjected, it may cause pipeline scaling, corrosion, and blockage of certain filtration devices during later filtration operations, ultimately reducing the effective life of the entire device[10]. With people's increasing attention to environmental issues, the use of biological methods to treat wastewater has also gradually gained attention.

The use of microalgae to treat wastewater is an environmentally friendly and sustainable technology that can not only remove organic pollutants from wastewater, but also obtain biomass energy. Chlorella vulgaris has a wide distribution, large biomass, simple requirements for growth conditions, and strong environmental tolerance [11,12]. The use of Chlorella vulgaris to treat fracturing wastewater can not only efficiently remove toxic pollutants such as organic and inorganic substances, as well as heavy metals, but also couple the algae cultured wastewater with the biodiesel production system after deep treatment, generating certain added value [13]. This technology has broad development prospects. However, there is currently very little research on the treatment of fracturing flowback fluid by microalgae. Mainly due to the complex composition and poor biodegradability of fracturing flowback fluid, the efficiency of biological treatment is relatively low. And the mechanism by which pollutants in the backflow fluid affect the growth and physiological metabolism of microalgae is still unclear, which hinders the development of large-scale treatment of fracturing backflow fluid technology using microalgae [14,15]. Therefore, the research on the treatment and utilization of fracturing flowback fluid by Chlorella vulgaris is of great significance. With the continuous development of biological treatment technology, the research and application of using microbial methods to treat fracturing fluid waste at home and abroad have been continuously promoted and expanded [16]. With the development of technology, many new processes for treating wastewater using biotechnology have also been introduced.

2. RESEARCH STATUS OF FRACTURING FLOWBACK FLUID TREATMENT TECHNOLOGY

Table 1. Advantages and disadvantages of fracturing flowback fluid treatment methods

Processing Methods	Advantages	disadvantages
Excavation and landfill		Causing pollution to the soil, it has been replaced
burn	The processing effect is good	Large initial investment and high cost
Storage of waste liquid pool		Large land area, causing overflow and soil pollution during the rainy season
solidification	The investment in treatment is small, and the treated fracturing waste liquid has very good properties	Long term management and large-scale stacking can cause harm to the surrounding environment
recycle	Low cost, fast processing speed	Generating new chemicals leads to secondary pollution
chemical method	The processing effect is good	High cost and potential for secondary pollution
Biological method	Low energy consumption, high efficiency, and green environmental protection	Long processing time

Fracturing operation is a major production increase measure for oil and gas wells, but it generates a large amount of fracturing backflow fluid. The wide range of on-site fracturing operations, multiple discharge points, scattered emissions, and difficulty in centralized treatment have caused management difficulties [17,18]. The current principle mainly focuses on direct discharge after meeting the standards. The fracturing flowback fluid mainly includes high concentration guar gum, various organic additives, and is difficult to treat. The main treatment methods currently used include solidification, waste liquid storage, incineration, reinjection, chemical methods, and biological methods (aerobic biological treatment, anaerobic biological treatment).

Compared with conventional physical and chemical methods for wastewater treatment, biological treatment of wastewater demonstrates better advantages, especially in the removal of elements such as C, P, S, and N from wastewater [19,20]. Biological treatment technology mainly relies on two aspects to achieve purification treatment of sewage:

(1) Microorganisms use organic pollutants as their own growth source. Microorganisms rely on their metabolic functions to oxidize and degrade organic pollutants during their own growth and reproduction under suitable environmental conditions;

(2) Microorganisms synthesize certain organic pollutants into their own cytoplasm. The cytoplasm can rely on physical flocculation to coagulate, precipitate or float together with other pollutants in water.

Although the biological method has a relatively long processing time, it eliminates the catalytic oxidation treatment unit, simplifies the treatment process, saves treatment costs, and has a lower cost.

3. MECHANISM OF ALGAE BACTERIA SYMBIOTIC TREATMENT OF OILY WASTEWATER

The relationship between bacteria and algae is complex, with both mutual promotion and mutual inhibition [21]. The symbiotic system of bacteria and algae is widely present in nature. Algae can provide oxygen for bacterial growth, promote bacterial growth, and bacteria will oxidize and decompose organic matter, releasing appropriate amounts of inorganic salts and providing inorganic nutrients for algal growth. The pollutants in the fracturing flowback fluid are essential elements that microalgae must absorb for their growth. During the photosynthesis process of microalgae, harmful substances in the fracturing flowback fluid are absorbed to purify water quality. Microalgae, in the process of purifying water quality, can use substances in wastewater to synthesize the proteins they need and produce a large amount of biomass [22,23]. The biomass produced can be used as biofuels and feed, achieving maximum resource utilization. In short, this method is environmentally friendly, easy to operate, and can also obtain renewable energy, with great potential for engineering promotion and application.

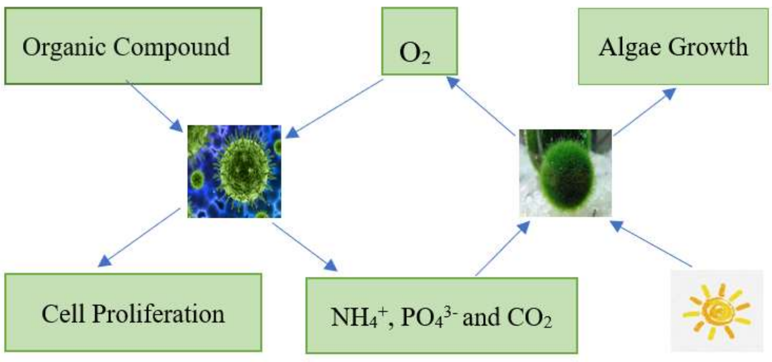

Figure 1. Symbiosis mechanism of algae and bacteria

4. MECHANISM OF ALGAE BACTERIA SYMBIOTIC PURIFICATION OF FRACTURING FLOWBACK FLUID

The treatment technology mainly utilizes biological absorption, degradation, and transformation of pollutants in soil and water bodies, reducing the concentration of pollutants to an acceptable level or converting toxic and harmful pollutants into harmless substances [24]. The symbiotic system of algae and bacteria is widely used to treat organic pollutants such as eutrophication, heavy metals, drugs, polycyclic aromatic hydrocarbons, and petroleum hydrocarbons that are difficult to degrade in water bodies. The main mechanisms for the removal of nutrients such as nitrogen and phosphorus involve assimilation, anaerobic ammonium oxidation, nitrification and denitrification, phosphorylation, etc. The main removal mechanisms for heavy metals, drugs, petroleum hydrocarbons, and other organic compounds are biological adsorption, biological enrichment, and intracellular and extracellular biodegradation.

1) Mechanism of nitrogen removal in algal bacterial symbiotic system

Assimilation is the main mechanism for inorganic nitrogen removal. Nitrates or nitrites are reduced to ammonia nitrogen and further synthesized into amino acids, which can be directly assimilated by microalgae [25,26]. In addition to assimilation, there are also volatilization, nitrification, and denitrification of ammonia. Nitrification involves the oxidation of ammonia to nitrite, which is then oxidized to nitrate by ammonia oxidizing bacteria (AOB), ammonia oxidizing archaea (AOA), and nitrite oxidizing bacteria (NOB). Denitrification is the process of reducing nitrate to nitrite, and then generating nitrogen gas through denitrifying bacteria under anaerobic conditions in aquatic environments. Anaerobic ammonia oxidizing bacteria and aerobic denitrifying bacteria (ADB) can directly denitrify under completely aerobic or anaerobic conditions. In addition, short-term nitrification and denitrification through nitrite can also effectively remove nitrogen. Organic nitrogen (such as amino acids and proteins) can be decomposed into ammonia, known as ammonification or mineralization reactions.

2) Mechanism of phosphorus removal in algal bacterial symbiotic system

Phosphorus plays a crucial role in the metabolism of microalgae and bacteria, especially in inorganic forms such as dihydrogen phosphate and dihydrogen phosphate, which can be phosphorylated to synthesize organic compounds (such as DNA, RNA, lipids, etc.). A large part of the assimilation of phosphorus in symbiotic systems is the production of ATP from ADP. Some types of microalgae and bacteria can absorb large amounts of phosphorus and store it as intracellular polyphosphates [27]. Phosphates can form hydroxyapatite, which is removed from wastewater by precipitation with calcium and magnesium ions at high pH values, and adsorbed on the surface through hydrogen bonding with extracellular polysaccharides secreted by microalgae or bacteria. Organophosphorus can be hydrolyzed into phosphate by extracellular enzymes secreted by bacteria, and then removed according to the above pathway. Similar to inorganic forms, organic phosphorus can bind with functional groups of extracellular polymers, adsorb onto algal bacterial symbiotic systems, and then further transform. Overall, the symbiotic system of algae and bacteria provides multiple pathways for phosphorus removal.

3) Mechanism for removing other harmful substances

The symbiotic system between bacteria and algae also exhibits the potential to remove recalcitrant organic compounds such as phenolic compounds and cyclic acids. Currently, phenolic compounds and their derivatives have caused a significant amount of environmental pollution. Although there is limited research on the mechanism of removal of phenolic compounds by algal bacterial symbiotic systems, many studies have shown that these systems have great potential for effectively degrading phenolic substances [28]. A study has found that Chlorella vulgaris can be used as an efficient biological cleaner for phenol. When the phenol concentration is below 300mg/L, algae have good phenol removal potential. Marquez et al. also found that phenolic compounds can be effectively removed by microbial communities of bacteria and algae.

5. CONCLUSION

The process of symbiotic treatment of wastewater by algae and bacteria has the advantages of low carbon, economy, and environmental protection. It can directly convert pollutants in wastewater into microalgae biodiesel to reduce carbon dioxide emissions, which is in line with the current national policy of carbon peak and carbon neutrality. It is a potential choice for achieving efficient wastewater treatment and resource recovery in future development. Microbial technology presents diversified characteristics in the field of sewage treatment. Microorganisms often utilize their own metabolism and adsorption capacity to remove pollutants from fracturing flowback fluids, but have not fully integrated the diversity characteristics of microorganisms and the resource utilization of pollutants. The interaction mechanism between different algae and bacteria in the symbiotic treatment of wastewater mainly involves nutrient exchange and chemical signal transduction. However, the current understanding of the mechanism is still not comprehensive enough, such as whether there is molecular level information exchange such as gene transfer, and the influence of different factors on the interaction mechanism. Further research is needed to provide ideas for further understanding the ecological interaction mechanism between algae and bacteria and designing more efficient wastewater treatment systems. Due to the unique advantages of microbial methods, the efficiency of wastewater treatment has gradually improved. With the continuous progress and deepening of research, we believe that future wastewater treatment methods can move towards more efficient and environmentally friendly fields.

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