

A REVIEW ON APPLICATION OF POLYMERS AS CHEMICAL ADDITIVES IN OIL AND GAS INDUSTRY

Abstract

The oil and gas sector, which forms the backbone of the world's energy supply, is constantly looking for ways to improve its sustainability and efficiency. In the drive to optimize the processes of oil and gas exploration, production, and refining, polymer additives have become crucial elements. The extensive usage of polymers as chemical additives in the oil and gas industry is examined critically in this review study. The examination starts by examining the many kinds of polymers used often in the sector, such as synthetic and biopolymers, and highlighting their unique capabilities. The discussion of polymers many uses follows, with an emphasis on their functions in drilling fluids, enhanced oil recovery (EOR) methods, scale and corrosion inhibition, and the reduction of formation damage. The essay also looks into how certain polymer characteristics, such as molecular weight, solubility, and chemical structure, affect how well they function in particular oilfield applications. Discussed are the advantages and drawbacks of using polymers while taking into account costs, the environment's impact, and compatibility with existing systems. The analysis also evaluates current advancements and advances in polymer technology, highlighting new patterns and prospective uses for the future. This thorough review provides insightful knowledge into realizing the full potential of polymer additives by addressing important issues and opportunities, ultimately assisting in the development of the oil and gas sector toward higher sustainability and efficiency.

Keywords: EOR, corrosion inhibitor, CMC, PAM, surfactants

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I. INTRODUCTION

Within the oil and gas industry, polymers have proven to be vital additions in a variety of applications. Polymers act as viscosifiers in drilling fluids, efficiently regulating the rheological characteristics of the fluid to enable effective drilling, hole stability, and cuttings removal. Reduced frictional pressure losses are possible because of polymers capacity to give drilling fluids pseudoplastic behavior when they circulate through the wellbore [1]. Additionally, polymer flooding has become a crucial EOR technology, enhancing oil recovery rates dramatically by raising sweep efficiency and raising the mobility ratio between injected fluids and residual oil. It depends on variables including reservoir parameters, temperature, salinity, and polymer content to choose the right polymer for these applications [2].

It is important to first look at the many types of polymers frequently used in order to fully understand the wide range of applications of polymers in the oil and gas sector. These comprise biopolymers including xanthan gum, guar gum, and cellulose derivatives, as well as synthetic polymers like polyacrylamide, polyethylene oxide, and polyvinylpyrrolidone. Different characteristics of each type of polymer make them suitable for different uses [3]. In many cases, synthetic polymers provide higher stability, resistance to deterioration, and consistent performance under a variety of circumstances. They are widely used in cementing processes, EOR methods, and drilling fluids. Biopolymers, on the other hand, provide environmentally favorable alternatives due to their biodegradability and reliance on renewable resources. These qualities make biopolymers especially ideal for use as additives in fracturing fluids and in applications in environmentally sensitive locations [4].

Additionally, polymers have demonstrated efficacy in preventing scale buildup and reducing corrosion, two significant problems in oil and gas production operations. Polymers effectively prevent the deposition of scale and lower corrosion rates, thereby extending the operational lifespan of manufacturing equipment [5]. They do this by establishing protective barriers on metal surfaces or by altering the crystallization behavior of ions that create scale. In addition to the aforementioned uses, polymers are also utilized to reduce formation damage from water-based drilling fluids, limit fluid loss during cementing operations, and alter the rheological characteristics of fracturing fluids. To get the best results, each of these applications has unique requirements and obstacles that require careful consideration while choosing and formulating polymers [6].

Current research and development initiatives have been working to find new ways to improve performance while also addressing the drawbacks of the oil and gas industry's use of polymers. To enhance their performance and adapt their behavior to particular issues in the oilfield, researchers are actively looking into innovative polymer formulations, such as nanopolymers and hybrid polymers [7]. Additionally, new opportunities for tailoring polymers to fit the constantly changing needs of the oil and gas sector have emerged as a result of developments in polymer synthesis methods, polymer modification, and polymer mixing. It has been demonstrated that combining conventional polymers with nanoparticles can improve their stability, viscosity, and adsorption behavior, which will increase wellbore stability and oil recovery rates [8].

This review chapter mainly focuses on application of the polymer additives in drilling fluids, EOR methods, and to reduce formation damage, scale, and corrosion. Hybrid polymers hold promise for the future since they combine various polymer features for better performance and increased adaptability. The investigation of hybrid polymers is anticipated to optimize upstream operations and spur advancements as the industry pursues innovation and sustainability.

II. APPLICATION OF POLYMERS IN OIL & GAS INDUSTRY

1. Drilling and Completion Fluid Operations: Drilling fluids are used in oil field operations to cool and lubricate the drill bit, clean the bottom of the hole, transport cuttings to the surface, manage formation pressure, and generally improve the function of the drill string and instruments in the hole. Most deep wells are drilled using drilling mud, a particular kind of drilling fluid. Water-based drilling muds (WBMs) and oil-based drilling muds (OBMs) are the two main categories of drilling fluids. The drilling and formation requirements determine the drilling fluid to be used. Spud muds, bentonite-containing muds, phosphate-containing muds, organic thinned muds (red muds, lignite muds, lignosulfonate muds), and organic thinned muds are all included in the class of WBMs known as "freshwater muds," which have a pH range of 7 to 9.5. [9] Bentonite a type of clay that swells when it absorbs water, providing viscosity and forming a filter cake. Barite a dense mineral used to increase the density of the drilling fluid to control pressure also various synthetic polymers may be used to adjust the viscosity and stability of the drilling fluid.

Water-soluble polymers are used as viscosifying agents in well-completion operations to regulate the filter loss of aqueous fluids. HEC, CMC, guar gum, and XG stand out among them. The fluid composition and the environment in which it will be used determine the type of polymer to be used. Utilizing organic polymers and the gravel-pack method, it is possible to limit the generation of sand, which is a major issue in oil fields and greatly reduces oil output from wells and, in some situations, can stop well production. Applying biopolymer as fluid additives can assist address this issue since it can increase oil recovery while lowering the cost of drilling, hydrofracking, and wastewater treatment. [10]

The kind of drilling mud utilised in a particular production well and the geologic conditions encountered when drilling and casing the well affect the choice of drilling chemicals. The vast majority of drilling fluids have a fresh- or saltwater base with additions that are intended to enhance at least one of the drilling mud's three primary functions:

- Formation control by circulating a fluid dense enough to "push back" on naturally pressurised fluids in the rock, pressure and fluids are achieved while drilling. Weighting agents are utilised, such as barite or baryte, BaSO₄, an extensively mined mineral that is finely pulverised in raw form. High-density fillers in paper and playing cards, as well as pigment in home and industrial paints, are alternative uses.[11]
- To prevent the wellbore from becoming blocked, cuttings from the drill bit must be

transported to the surface, which calls for a viscosity-increasing substance like bentonite clay. Barite is maintained in suspension in a water-based mud by increasing viscosity. A clay called bentonite is created when volcanic ash undergoes a natural geochemical transformation. Alternative applications include cat litter, beauty products, food additives, and other requirements needing adsorption or enhanced viscosity [11].

Additives that alter the behaviour of minerals are necessary to stabilise the formation and avoid either the chemical or physical modification of components like swellable or migrating clays in the rock matrix or the physical collapse of unstable rocks near the wellbore wall. These components could comprise cellulose derivatives or polymers like xanthan gum to reduce fluid loss into the formation as well as potassium chloride or sodium chloride mixed with connate fluid to reduce clay reactions [11].

- 2. Well Stimulation Operations:** Hydraulic fracturing (fracking) is a hydrocarbon extraction method that is utilized to recover crude oil and/or gas from constrained underground formations. This method of energy recovery involves injecting a water-based fluid under intense pressure to fracture or cause fissures in the reservoir rock. Once the rock has been broken, the fluid seeps into the fissures and enlarges them away from the wellbore. The reservoir's surface area and hydraulic conductivity are increased by the created fractures, allowing for better oil and gas movement and recovery. In various stages of the hydraulic fracturing process, polymers having linear or crosslinking structures and properties as a gelling agent are utilized. When a well is being drilled, polymers are added to the drilling muds as lubricants, which is the first time they are used [12].
- 3. Enhanced Oil Recovery:** By enhancing sweep effectiveness and speeding up oil output, polymer flooding results in enhanced oil recovery. The infectivity of polymer solutions, however, is of some concern due to their increased viscosity and is crucial to comprehend in order to forecast incremental oil recoveries. To enhance oil production rates, high polymer injection rates must be attained.

The past two years have seen the injection of poly-acrylamide polymers in the Matzen field (Austria) field test. The viscoelastic characteristics of the polymer solutions led to a notable rise in apparent viscosity during coreflood tests with these polymers. Furthermore, it was discovered that the polymer solution degraded severely at high flow rates. There were flow experiments through fractures in addition to core flood studies.[13]

Because the molecular chain of polymeric surfactants contains hydrophobic units, they interact more intra- and intermolecularly than typical polymers, improving their solution characteristics. The molecules are "drawn" together by these functional groups via hydrogen bonds and van der Waals forces, establishing linkages in the solution that, depending on the density of the molecules in solution, can propagate and create an extensive network. As a result, they form tensile connections that result in an improvement in bulk viscosity and elasticity. With increased concentration, this effect gets more pronounced, and at a certain point, the principal interaction turns into an intermolecular one, causing an apparent spike in the viscosity profile. With higher

concentration, molecules are closer to one another, which facilitates easier contact. The term "critical association concentration" refers to the concentration that corresponds to this situation. [14] It was cited in the paper that Bohlin Gemini rheometer was used to evaluate the viscosity of the synthetic polymeric surfactant solution with a bob and cup geometry setup.

The solution was put in the cup, and the shear rate was gradually increased by rotating the bob or inner cylinder to measure the torque, allowing one to calculate the shear stress. The polymer powder was dissolved completely in water for the entire night in order to prepare a polymeric surfactant solution with a concentration of 6000 ppm. A polymeric surfactant with a 6000 ppm concentration has its viscosity evaluated against shear rates between 0 and 1000 s⁻¹ and salinity effects between 0.5 and 4 wt%. In order to examine the viscosity versus shear rate flow curve, many mathematical models, including the Bingham plastic, Power law, and Herschel Buckley models, were used. [15]

- 4. Control Hydrates & Corrosion:** Polymers manage hydration and corrosion risks and interoperability problems. The outcomes showed that waterborne polyurea/urethanes (WPUUs) performed well in postponing induction time (up to 17 times) and decreasing hydrate growth rate (up to 7.7 times) in comparison to water. Additionally, the hydrates produced in the WPUUs system at a water-cut of 60% were equally distributed in the liquid phase like slurry, making them especially suitable for the flow in pipes. In a highly corrosive environment (2 M HCl), the WPUUs prevent the corrosion process, as demonstrated by weight loss, SEM-EDX, profilometer, and quantum chemistry investigations [16]. This study presents for the first time the compelling arguments for employing aqueous polymers as potential kinetic/anti-agglomerant inhibitors of methane hydrate and corrosion.

III. FIELD TRIALS

The usage of high molecular weight non-hydrolyzed and hydrolyzed polyacrylamide (PAM and HPAM) as a viscosity enhancer in EOR and, more recently, as a friction reducer in large volume hydraulic fracturing, has increased during the past eight years [17]. At contrast to polymer nanocomposites based on carboxymethylcellulose (CMC), nanocomposites based on PAM together with Al/Cu nanoparticles were more effective at displacing oil, giving an additional oil recovery of about 35–40%, according to a trial project at the Bibiheybat field, Absheron Peninsula. [18]. Al nanopowder in the mixture encourages gas formation, which causes microcracks to speed up the flow of oil through the reservoir. Cu nanopowder gives it strong bactericidal effects and raises the recovery factor. Al and Cu nanoparticles have an impact on oil, increasing its viscosity and, as a result, the fluidity of the oil [19].

Polymer gels have been widely used for profile control, formation plugging, water shutoff and lost circulation control in oil-gas engineering due to their suitable viscoelasticity and deformability [20]. They serve as a sealant and a water-permeability modifier. By filling in fractures, they typically decrease the relative permeability of water without affecting the permeability of oil [21]. In extreme conditions of high salinity and high temperature reservoir (above 480°F), it was estimated that polyvinyl alcohol as a gel polymer would be stable for superior flooding and can reach upto 50% recovery in operating wells [22].

By implementation of surfactant/polymer flooding by developing full field model of middle eastern sandstone reservoir, the most economical design was achieved with high concentration of polymer and low concentration of surfactant [23]. According to a relevant investigation, the refined management of the polymer injection process in the SL Oilfield, China, resulted in an increase in the quantified rate of single well concentration and a decrease in water cut [24].

IV. PROSPECTS AND CHALLENGES

The biggest issue with the rapidly expanding industrial sector is maintaining the environment and creating environmentally friendly multipurpose materials, notably for the petroleum industry. Since these materials are made of natural polymers, their sustainability is ensured. Degradation of polymer through mechanical, thermal and high salinity condition, reduction in fracture permeability and adsorption of polymers in fracture and matrix are some of major concern in using a polymer as an additive in fracturing fluids [25]. Due to production from deep onshore conventional and unconventional formations as well as ultra-deep water applications, there is an industry-wide demand for the development of degradable guar-based solutions that leave fewer residues after degradation, as well as breakers that can be applied under very high temperatures (300°F and above), shear rates, and severe pH conditions [26].

Even though residual PAM has not been recognized as being a significant barrier to reuse, the degraded polymer may clog formation pores and minor cracks, decreasing the permeability of the formation for gas and oil [27]. The structure-property connections of frequently employed High Performance polymers (HPPs) and ongoing research on these polymers have both been explored.

There are specific types of polymers that can be employed with or without additives, depending on the intended material property, to improve the material's safety, durability, and performance. Although there are many prospects in the oil and gas sector for HPPs, the complicated surroundings (high temperature, high pressure, high salinity, etc.) can also present a number of technical difficulties [28]. The improvement on the HPP properties, use of AM in manufacturing, and expansion on the number of applications are currently being investigated by many materials scientists worldwide [29].

V. EVALUATION OF ENVIRONMENTAL IMPACT

The findings of all the research that has been published to date indicate that plant-based polymers have promising potentials for use in oilfield operations [30]. Therefore, it can be inferred that combining the use of these resources with the manufacture of oilfield chemicals will aid in developing a clever method of managing its wastes.

Additionally, it will aid in lowering environmental pollution brought on by the after-use disposal of oilfield chemicals [31]. There are numerous treatment technologies that could be used to get rid of or degrade PAM, but their effectiveness hasn't been tested, especially regarding PAM fragments. PAM concentrations could be reduced by more than 95% using a membrane bioreactor in conjunction with hydrolysis-coagulation[32]

VI. CONCLUSION

Polymers have proven to be highly valuable chemical additives in the oil and gas industry. Their diverse range of properties and functionalities make them indispensable for enhancing various aspects of oil and gas operations. Polymers play a crucial role in preventing and mitigating flow-related challenges, such as paraffin, asphaltene, and hydrate formation. They effectively reduce viscosity, stabilize emulsions, and inhibit the agglomeration of solids, ensuring smooth and efficient flow throughout the production and transportation processes. Polymers are extensively used in enhanced oil recovery (EOR) techniques to improve the sweep efficiency of injected fluids.

Their ability to increase viscosity and reduce mobility ratios helps to displace more oil from the reservoir, leading to higher recovery rates. In hydraulic fracturing operations, polymers are employed as key components of fracturing fluids. They assist in creating and maintaining fractures, improving proppant transport and placement, and ultimately enhancing well productivity. Polymers serve as essential components in drilling fluids, aiding in borehole stability, carrying cuttings to the surface, and reducing fluid loss. Their high thermal stability and compatibility with other additives make them ideal choices for challenging drilling environment. Polymers also act as effective corrosion inhibitors, providing a protective barrier on metal surfaces and preventing the detrimental effects of corrosion on equipment and infrastructure.

By sequestering scale-forming ions, polymers help prevent scale deposition on production equipment and pipelines, reducing the risk of flow restrictions and operational inefficiencies. The use of polymers in the oil and gas industry can lead to more sustainable practices, such as reduced water consumption in EOR and lower chemical dosages due to their high efficiency.

Overall, when used judiciously, polymers undoubtedly contribute to optimizing production, minimizing operational challenges, and improving the overall efficiency and sustainability of oil and gas operations. A reservoir's mobility ratio between the displacing fluid and the displacing fluid improves when polymer is used as the reservoir's primary feedstock rather than regular water. The hydrolyzed form of the synthetic polymer polyacrylamide and the biopolymer xanthan are used for this purpose in the oil and gas sector. Polyacrylamide is susceptible to contamination from salt and high temperatures, though. Additionally, it harms the environment because it is synthetic.

The biopolymer xanthan has a degradation problem, and both are relatively expensive. It is vital to look within and apply creative thinking to develop new, improved polymers that can address these difficulties due to the low price of crude oil, the high cost of extraction, and the challenge of drilling new wells.

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