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Polyacrylamide Polymer Gel Systems for Conformance Control Technology: A Review

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Abstract

Low oil extraction and early high water production are caused in part by reservoir heterogeneity. Huge quantities of water production are prevalent issues that happen in older reservoirs. Polyacrylamide polymer gel systems have been frequently employed as plugging agents in heterogeneous reservoirs to regulate water output and increase sweep efficiency. Polyacrylamide polymer gel systems are classified into three classes depending on their composition and application conditions, which are in-situ monomer gel, in-situ polymer gel, and preformed particle gel (PPG).

This paper gives a comprehensive review of PPG's status, preparation, and mechanisms. Many sorts of PPGs are categorized, for example, millimeter-sized preformed particle gels, microgels, pH-sensitive cross-linked polymers, swelling polymer grains, and Bright Water®. In addition to this, the most important factors to consider while assessing gel performance, such as swelling capacity, PPG injectivity, and plugging efficiency, are studied carefully. Not only are the design considerations and field application of PPG mentioned, but also the advantages of PPG are demonstrated. Gels have been used in around 10,000 wells worldwide to reduce the fractures permeability or super-high permeability channels during water and polymer floods.

Keywords: Polyacrylamide, In-situ gel, preformed particle gel, Conformance control

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1- Introduction

As the rate of new reservoir discoveries slows, enhanced oil recovery (EOR) methods for older oilfields become more important. EOR techniques often include the injection of substances not found inside the reservoir, like foams, surfactants, polymers, solvents, etc. The reservoir's heterogeneity is a significant factor in determining poor oil recovery and rapid extra water cut. A lot of mature reservoirs have cracks or high-permeability pathways that were caused by flooding. These are called thief zones [1].

Waterflooding has been used as a secondary recovery strategy for many decades. However, owing to long-term waterflooding operations throughout numerous fields, a huge permeability difference, fractures presence, injected water be apt to inflow along the slightest resistive channels, resulting in low sweep efficiency and the loss of significant oil amounts. The effects of this issue contain a quick drop in oil production, the requirement for separation of water and oil, more money spent on pumping, treating, and disposing of water, and early well abandonment[2]. The yearly cost of separating, handling, and disposing of undesirable water production is over $50 billion[3].

Conformance control is described as the use of techniques within reservoirs and wellbores which minimize unexpected water production and maximize hydrocarbon oil recovery.

It accomplishes these objectives by decreasing or sealing the water generated by high permeability formations, fractures, and fracture-like structures. To solve excess water production issues, three primary conformance control techniques are available: mechanical, completion, and chemical solutions[4]. Numerous solutions have been used to address the issues of excessive water production and EOR methods. They include flooding with polymers, flooding with alkaline surfactants, foam flooding, etc. Polyacrylamide (PAM) polymer gel therapy is a popular and cost-effective approach among them.

Gels have found widespread usage as fluid-flow blocking agents in the oilfield because they are often a very cost-effective blocking and/or permeability-reducing solution for conformance control applications. A more traditional simplification of gel is as "a jelly-like material generated when a colloidal solution coagulates into a semisolid form." Gel is a word used in the current oil industry and technical literature to refer to the elasticity and semisolid substance formed by chemically crosslinking water soluble polymers in an aqueous solution. Gels are often manufactured using cheap commodity polymers[5].

Gel treatment is a popular EOR technique that is useful for enhancing the recovery of oil in mature reservoirs having fractures or fracture-like structures.

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The basic function behind gel treatment is that it can plug or significantly reduce the permeability of the fractures and the permeability contrast within the zones, which reduces the water flow preference through the fractures and water channelling. The performances of the water sweep and oil recovery are therefore improved. There are three types of Polymer gel technology, which are in-situ monomer gel, In-situ polymer gel, and preformed particle gels. Studies reveal that PPG is environmentally friendly, strong and small-controllable, stable over longer durations, and also very likely able to overcome several limitations inherent in in-situ gelling. Reservoir minerals and salinity of the formation water have no effect on its thermostabilization.

2- Types of Polymer Gel Treatment

Gels are often categorised according to their formulation, properties, and intended use. There are three types of Polymer gel technology, which are in-situ monomer gel, In-situ polymer gel, and preformed particle gels.

2.1. In-Situ Monomer Gel

For conformance control, several older applications employed an acrylamide monomer system which polymerized in-situ. The monomer plus crosslinker mixture exhibited an initial viscosity equivalent to water when brought into formation with 4 percent to 10 percent total dissolved particles (i.e., 1–1.3 cp). It might penetrate all regions in the formation's in-depth regions because of its initial low viscosity. However, controlling monomer gelation at high temperature operation conditions was challenging, since monomer gelation is a free-radical started fast process. To avoid early gelation, a retardant was frequently used[1].

2.2. In-situ polymer gel

In-situ gel operation is a widely utilized technique of conformity control in the oil industry. In the 1970s, Phillips Co. (now ConocoPhillips) used partly hydrolyzed polyacrylamides (HPAM) and aluminum citrate to create the first in-situ polymer gels[6]. Since then, interest in in-situ polymer gel solutions has increased.

In-situ gel treatments are crosslinked polymers made up of polymers, crosslinkers, as well as additives. The crosslinking agent attaches itself to two neighbouring polymer molecules, chemically or physically, connecting them together. A gelant is the liquid form of this compound. The gallant is injected into the zone through an in-situ mechanism, and the gel is formed under reservoir conditions. Under different circumstances, including rising temperature and changing pH, the gelant may crosslink and create a gel. Gel strength may be controlled by both the composition of the gelant and the surrounding environment[7].

The researchers noted that although the strength factor of injected gelant is often significantly greater than that of injected polymer, in-situ gel field testing revealed that this approach may sometimes result in increased damage to small permeability un-swept oil regions. While in-situ gel system is cost-effective and thus appealing, they do have some inherent disadvantages, including restricted control over time of gelation, challenges dominant the stabilization and resistance of the composed gel, adsorption of materials on the surface of rock, reactions with water of formation, and mitigation and dissolution of polymer throughout reservoir[8].

Polymer gels are divided into bulk and weak gels based on their variety of gel strengths, which is indicated by viscosity. The viscosity of bulk gels is often more than 30000 cp, but the viscosity of weak gels is between 100 and 10000 cp[9].

2.3. Preformed Particle Gel

Preformed particle gel (PPG) was introduced in 1996 by the Research Institute of Petroleum Exploration and Development (RIPED) of PetroChina as a novel sort of conformance control technology. For conformance control reasons, many different types of PPGs have already been established recently. Typically, preformed particle gels are prepared using a monomer like acrylamide, a crosslinker, an initiator, and other ingredients. The gel is manufactured in ground facilities, dried, crushed into tiny particles, and then sieved to pick up the particles of the desired size. PPGs vary in size from micrometres to centimetres[10].

Preformed gels are created on the surface prior to injection and are injected into the reservoir as particulates; no gelation happens in the reservoir. PPG is capable of absorbing a considerable amount of an aqueous mixture; the polymers should be just weakly cross linked to allow the polymer chains to grow in a vast area. PPGs may expand to hundreds of times their volume in liquids, making it difficult to discharge the absorbed liquids under pressure. After swell, the PPG is pumped into the formation to plug or minimize the permeability of fractures, fracture-like channels, or large permeability zones[11].

All prepared particle gels utilized for conformance control are members of the superabsorbent polymer family (SAP). SAP is a three-dimensional network of cross-linked polymer series which have the capability to absorb or ingest more than ten times their mass in water or aqueous solutions[1].

The first effective field use of PPG occurred in 1999 at the Zhongyuan Oilfield. PPG has been employed successfully in China for over 5,000 wells to minimize water cut or polymer output in mature waterflood zones[11].

a- Preparation of Preformed Particle Gel

The processes for synthesizing PPG in the laboratory are described by **Bai. et al.** [10] as below:

- Make an aqueous mixture that has acrylamide, a crosslinker, an initiator, with other ingredients based on a specific formula.
- At a certain temperature, crosslink the solution to create a bulk gel.
- Divide the bulk gel to tiny pieces and dry at 70°C
- Depending on the field application requirements, mechanically grind the dried gel fragments into micrometer-sized or millimeter-sized particles.
- Sieve the particles until the required size is achieved.

b- Mechanisms of PPG Treatment

Gel treatment is a common EOR method that is useful for enhancing the recovery of oil in mature reservoirs having fractures or fracture-like structures. The principle of gel treatment is that it may plug or greatly decrease the fracture permeability and minimize the permeability contrast inside the zones; consequently, the water flow preference via the fractures is lessened and water channeling is minimized. As a consequence, the water sweep performance and recovery of oil are enhanced.

The use of particle gel improves sweep performance in heterogeneous reservoirs. While typical polymer flooding may also increase sweep competence, the difference between polymer flooding and gel therapy and is significant. Polymer solutions are designed to perforate deeply into unswept zones or inadequately swept zones with low-permeability, whilst gelants inject into areas with high-permeability and avoided in low-permeability zones[12]. By way of explanation, the polymer acts like as an agent for mobility control while the PPG acts as a blocking agent.

PPG is synthesized at the surface facility and pumped into forms as a single component. These swelling particles vary significantly from rigid particulates in that they are flexible and deformable, allowing them to access via throats of formation pore which are far minimal than themselves. As a result, they may deform and enter through huge channels or cracks located deep inside the zone of high permeability. If a small quantity of PPG is applied near the wellbore, the following water will skip the pumped gel and revert to earlier water routes in the zones with high permeability, indicating that the curing has no influence on production of water and hydrocarbon. A large quantity of PPG, particularly if it can be deployed among wells, is far more efficient in sweeping up more oil [13].

The upper part of Fig. **1** illustrates the effect of pumping a small quantity of PPG gel which will be located near wellbore and lead to block the beginning of a high permeability zone which result the following water will skip the pumped gel and revert to earlier water routes in the zones with high permeability.

On the other hand, the lower part of Fig. **1** explains that a big quantity of injected PPG gel has a more efficient in sweeping up more oil since the waterflooding will flow through the low permeability zones which have an unswept oil.

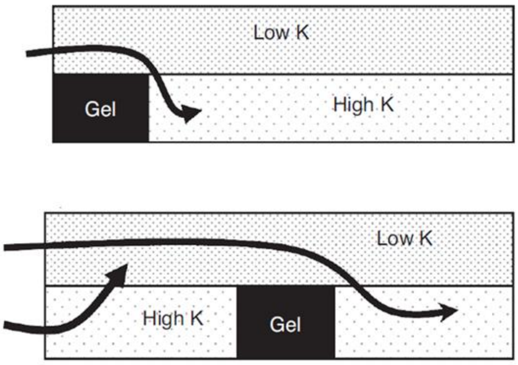

Fig. 1. Mechanism of PPG treatment [13]

c- Types of PPG

Various kinds of PPGs have diverse particulate sizes based on their application, swelling time, and swelling ratio. There are micro to millimeter-sized PPG[10], microgels[14], pH-sensitive cross-linked polymers[15], swelling polymer grains[16] , and Bright Water®[17].

Microgels, pH-sensitive crosslinked polymers, swelling polymers, and Bright Water are examples of small particle gels which they have sizes ranging from nano to micrometer that can be utilised to decrese production of water and control profiles in heterogeneous reservoir which have permeability less than a darcy. The techniques contain altering relative permeability, and blocking big pores[18].

Millimeter-sized particle gels are often used in fractures or channels resembling fractures with permeability greater than a few darcies. In PPG treatment, the principal strategy of conformance control is to partly or completely block the high permeability zone. Extensive laboratory testing has shown that millimeter-sized particles cannot be transported via porous media under typical reservoir pressure gradients due to the particle size being too big relative to the matrix pore throat. As a result, the trapped particles agglomerate and create a form of gel cake at the surface of rock, increasing the pressure gradient significantly. This pressure gradient will surpass threshold pressure necessary for particulate extrusion via the open[18].

d- Properties of PPG

When exposed to water, PPG often swells dozens to hundreds of times its initial size. Particles become flexible and deformable upon swelling. The swollen particles are injected into the desired medium at concentrations ranging from 1000 to 20,000 parts per million (ppm) and either block or decrease the permeability of highly permeable media such as fractures and channels[19].

According to researchers' laboratory experiments, the primary factors for assessing gel performance swelling capacity, Injectivity of PPG, and plugging efficiency

- Swelling Capacity of PPG

Swelling capacity refers to the amount of water or brine that a certain quantity of dry PPG can absorb. The following two techniques for determining swelling capacity have been published in the literature:

- Volumetric Method

Preformed Particle Gel with the required concentration is mixed in the proper brine which made with a 100 mL gradient colorimetric tube. After that, the PPG suspension is placed in bath of water that has been preheated to the proper temperature. At uniform time periods, the volume of swollen PPG is measured until its alteration is minimal. The swelling proportion during any point in time can be computed using the equation below[20]:

$$SR = \frac{V_s}{V_d} \times 100 \quad (1)$$

Where:
SR: swelling ratio (cc/cc)
V_s: the PPG volume after swelling (cc)
V_d: the initial dry volume of PPG (cc)

- Gravimetric Method

For the specified time period, a weighed amount of dry PPG is immersed in the specified amount of water. Following that, a paper filter is used to separate the residual water from the swollen PPG. Then, the PPG net weight is calculated. The below equation is used to measure the ration of swelling[21]:

$$SR = \frac{M_s - M_d}{M_d}\, x\, 100 \quad (2)$$

Where:
M_s: the weight after swelling
M_d: the weight of dried PPG

The volumetric method technique isn't a trustworthy measurement method. Because of the water amount placed between the gels particulates are comprised in the total volume, the gravimetric method technique eliminates this inaccuracy, resulting in a more efficient method than the volumetric method.

- Injectivity of PPG

The injectivity of a PPG is utilised to determine if PPG can pass via the core or sandpack or to determine the complexity of injected PPG. PPG injectivity equals the steady flow rate divided by the steady injection pressure in the laboratory[22].

Coste et al. explained that particles might pass through pore constraints in three ways: deforming and passing, shrinking and passing, or breaking and passing[23].

In addition to this, **Bai et al.** was found that when PPG moved across porous surfaces, there were three different transport patterns: pass, broken and pass, and plug[24].

When pressure gradient is larger than threshold pressure, PPG may move via a narrower pore throat size. The threshold pressure wanted to move a particle throughout a porous media is governed by the particulate and pore throat diameter proportion, the stiffness of the swelling PPG, and the porous medium structure[24].

- Plugging Efficiency of PPG

The performance of gel therapy focuses greatly on the capacity of the gel to minimize the formations permeability or fractures[25]. Plugging efficiency and water residual resistance factor are typically employed to assess PPG implementation in single core or sandpack blocking competence trials. The plugging efficiency is known as the proportional decrease in permeability after PPG treatment. Water residual resistance factor is a ratio of water permeability before and after PPG treatment. Frrw is calculated in the experiment by dividing the pressure drop of the water injection after PPG treatment and pressure of the injected water before gel therapy.

$$F_{rrw} = \frac{Pressure\ drop\ after\ treatment}{Pressure\ drop\ before\ treatment} \quad (4)$$

$$F_{rrw} = \frac{K_b}{K_a} \quad (5)$$

Where:
F_{rrw} is water residual resistance factor
K_b is permeability of water before treatment
K_a is the permeability of water after treatment
The relationship between F_{rrw} and plugging efficiency is

$$E = \left[1 - \frac{1}{F_{rrw}}\right] * 100 \quad (6)$$

It is preferable to use F_{rrw} to indicate the decrease in water permeability caused by gel[22].

Plugging efficiency rises with increasing PPG strength, size, and concentration in the sandpack model[26].

e. Environmental Parameters Effect's on PPG Properties

The status of the reservoir into which PPG will be injected has an important effect on the properties of the PPG. The environmental parameters such as temperature of the reservoir, salinity of the formation brine, and pH of the formation brine are the main parameters that affect the pumped PPG.

- Temperature

When temperature increases by more than 80 C, the swelling capacity of the preformed particle gel grows[10]. Temperature may have an effect on a PPG treatment's thermostability. PPGs are normally thermally stable for more than a year in field applications when used under reservoir conditions[22].

- Salinity

PPG mixed with brine with low salinity exhibited a lower strength and a higher ratio of swelling than gel prepared brine with high salinity [10]. PPGs have great salt resistance and are hence suitable for usage in high-salinity reservoirs. PPGs are more thermostable in high salinity water because of increased crosslinker density, which results in a decreased swelling ratio, which strengthens the particles. Furthermore, increasing gel strength has another benefit: it improves the efficiency of plugging[27].

- pH

At low pH values (less than 7), the release of proton ions protects negatively charged groups from the electrostatic repulsive force. As a result, raising the pH to almost neutral circumstances, results in a rise in the capacity of PPG swelling. Additionally, elevating the pH to an alkaline environment has no discernible effect on swelling capacity[10].

f. PPG Treatment Design Consideration

Considerations for the design of the PPG treatment process include injection equipment, injection procedure, and injection parameters. PPG treatments need simple injection facilities since these gels typically contain just one ingredient throughout the process of injection, and bullhead is often employed to achieve selective permeation of gel particulates. PPG pumping is a multi-stage procedure that includes a gradual growth or reduction in the PPG size particle and a PPG concentration. The size of particle and concentration of PPG suspension determined in the initial step are significant because they serve as a baseline for curing planning. PPG particulate size, volume of injection, and concentration of PPG suspension are all injection parameters.

- Particle size

Suitable particle size selection is critical for PPG therapy efficacy. The particle size of PPG must be tiny sufficient to penetrate and pass through the zone, but large adequate to fill the channels with high permeability zones. Field operators frequently depend on PPGs' stiffness for granted and use particulate sizes up to 1/3 the size of the pore throat. Indeed, PPGs vary significantly from stiff particles in that they expand when exposed to water or brine, and the swelled gel particles are flexible, allowing them to flow smoothly down a pore throat[22]. According to one experimental study, PPGs can permeate through pore throats 0.175 times the diameter of the swollen PPG[24].

In the field operations, there are now two basic kinds of injection processes that are widely used in terms of particle size.

The first form involves initially injecting big particles, followed by many stages progressively rising from tiny to large particles according to the reaction of injection pressure. The purpose of the first injection of big particulates is to build gel cakes on the faces of zones with low-permeability, preventing subsequent tiny particles from accessing and harming un-swept oil regions[10]. Anyway, if the starting particulate size is selected incorrectly, the injection pressure may quickly rise to reach formation fracture pressure, which could cause fractures inside the formation.

The second method of injecting PPG is to use numerous stages to inject particles straight from tiny to big sizes. Because this approach allows the front of the PPG slug to enter deeply and avoids the need to inject gel breaker after therapy, over 90% of injection operations use the latter technique[11].

- Injection volume

A significant volume of gel injection is critical for increasing treatment efficiency on both a technical and economic level, most notably in terms of incremental oil recovery. Numerous approaches were explored to determine the appropriate volume of PPGs to inject. Depending on the treatment radius, some operators like to calculate the volume of injection[28]. It is also thought that fracture-like channels with high permeability are found in most of the wells that are treated. This means that the flow geometry may be linear rather than radial[12].

- PPG Suspension Concentration

When the quantity of gel is constant, it may be pumped through a huge slug volume with a low PPG concentration or a little slug volume with a big PPG concentration. Usually, it is preferable because it permits particles to proceed freely and penetrate greater into the zone, while high PPG concentration tend to constrict particulates around the wellbore[22].

g. Advantages of PPG

PPGs have gained widespread acceptance and increased operator usage because of their distinct benefits over traditional bulk gel systems, which include the following:

- They are synthesized before formation contact, which eliminates many disadvantages associated with in-situ gelation systems, including uncontrolled gelation periods, fluctuations in gelation owing to shear degradation, and gelant changes produced by interaction with reservoir materials and fluids.
- They have a regulated strength and size, are environmentally acceptable, and are stable in nearly all reservoir elements as well as formation water salinity.

- They have a preference for entering fractures or fracture-feature channels whilst reducing gel penetration in un-swept regions.
- They typically contain just one component upon injection, simplifying the procedure of treating PPGs compared to regular in situ gels.
- Unlike typical in situ gels, which are readily impacted by the salinity of the produced water, PPGs may be created using produced water without affecting the gel's stability, therefore conserving freshwater and safeguarding the environment[29].
- When PPG is exposed to water, it can expand several times its original size, but when swelled particle gels are submerged in oil, the size of the gel may decrease to less than half of its initial volume. This feature is extremely advantageous for reservoirs with remaining oil production potential since the shrinking of the particle volume enables the oil to more easily breakthrough[30].

h. Field applications of PPGs

PetroChina started using PPGs for conformity control in 1997. Between 1997 and 2013, approximately 4,000 wells in most of China's oilfields were injected with PPGs or PPGs in combination with other gels, involving sandstone reservoirs and carbonate reservoirs with a temperature range and formation salinities[18]

PPGs were used at the Zhongyuan oilfield in a high-salinity, high temperature reservoir since in-situ gel was not practicable under these difficult circumstances. For many years, the sandstone reservoirs had been flooded, and the issues they faced were quick connection between injection and production wells as well as severe vertical heterogeneity. The PPG application was successful, and it became the principal means of compliance improvement in this oilfield[18].

The Shengli oilfield, which is located in China, produces an enormous amount of sand, which was treated with PPG. In 1999, two wells in the Shangdian reservoir were treated using PPGs. The Shangdian reservoir is a sandstone reservoir with faulted blocks, unconsolidated sand, and a lot of salinity, making it an unsuitable option for traditional gel treatments. Following the treatment, profile surveys showed that both vertical fluid distribution and extra oil production had gotten better[18].

PPGs have been used in the USA since the early 1990s, although only a few outcomes are publicly available. PPGs have been employed at West Texas's Anton Irish Field. This carbonate reservoir deposit was subjected to a CO_2 flooding operation beginning in 1997. However, fast leakage of CO_2 and water via conduits prompted the operators to investigate other conformity control techniques. Following numerous fruitless efforts, PPGs were employed to cover the conduits and inhibit CO_2 and water cycling, resulting in lower CO_2 and water generation and increased incremental production of oil. This demonstrates that the gels were successful in filling the reservoir's voids[31].

A case study was done on the PPGs utilised in the Kelly-Snyder field in Scurry County, Texas, where preformed particle gels up to 6 mm were effectively injected into numerous wells to address their short circuits and regulate CO_2 production. This application made the injection pattern better, which led to less CO_2 being released and more oil being produced[32].

3- Conclusion

Polyacrylamide polymer gel had a considerable influence on water shut-off and profile control operations, the plugging of open wellbores, zone or well abandonment, and other applications. There are three types of gel treatments that are classified in this paper. The most dominant type is PPG since it has distinct benefits over traditional bulk gel systems, such as controlling gelation time, taking place at the surface before injection, containing just one component upon injection, and being environmentally friendly.

According to the following process, PPG is made by: creating bulk gel, separating the gel's particles, drying the sliced materials. The dry particles are ground, then the particles are sieved to the required size. Mechanisms of PPG treatment include the deforming and entering of PPG through huge channels or cracks located deep inside the zone of high permeability to block these regions and allow water to sweep the oil in the low permeability zones.

The swilling capacity of PPG is calculated based on two methods, which are the volumetric technique and the gravimetric method. The gravimetric method is a more efficient method than the volumetric method. The residual resistance factor is calculated in order to determine the plugging efficiency of the used gel.

In most situations, swelling ration of gel grows with rising temperature (below 100°C), lowering salinity, and growing pH. In addition, when SR rises, the gel strength reduces. The findings of PPG treatment experiments reveal that there is an optimal PPG size for efficiently plugging the high-permeable area while causing the least amount of harm to the low-permeable area. This ideal size varies from one type of PPG to the next.

Finally, around 10,000 wells have employed gels successfully to decrease super-high permeability channels or fracture permeability during water and polymer floods.

Nomenclature

E	Plugging efficiency
EOR	Enhanced oil recovery
Frrw	Water residual resistance factor
HPAM	Partly hydrolyzed polyacrylamide
K_a	Permeability of water after treatment
K_b	Permeability of water before treatment
M_d	Weight of dried PPG
M_s	PPG weight after swelling
PAM	Polyacrylamide
SR	Swelling ratio
V_d	Initial dry volume of PPG
V_s	PPG volume after swelling

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أنظمة جل البولي اكريلاميد للتحكم بالمطابقة : مراجعة

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الخلاصة

يعود سبب انخفاض استخراج النفط و الإنتاج المرتفع للمياه المصاحبة للنفط في وقت مبكر من بدء الانتاج إلى عدم تجانس المكمن. تعتبر الكميات الهائلة من إنتاج المياه مشكلة منتشرة تحدث في المكامن القديمة. تم استخدام نظام البولي أكريلاميد بشكل متكرر كعامل اغلاق للمكامن غير المتجانسة لتنظيم إنتاج المياه وزيادة كفاءة انتاج النفط. يتم تصنيف أنظمة البولي أكريلاميد إلى ثلاث فئات وفقًا لتكوينها وظروف التطبيق: هلام مونومر في الموقع ، وهلام بوليمر في الموقع ، وهلام جسيمات مُشكل مسبقًا (PPG).

تقدم هذه الورقة مراجعة شاملة لحالة PPG وإعدادها وآلياتها. يتم تصنيف العديد من أنواع PPGs ، على سبيل المثال ، المواد الهلامية مسبقة التشكيل بحجم مليمتر ، والميكروجيلات ، والبوليمرات المتقاطعة الحساسة لدرجة الحموضة ، وحبيبات البوليمر المتضخمة ، و Bright Water®. بالإضافة إلى ذلك ، تمت دراسة أهم العوامل التي يجب مراعاتها أثناء تقييم أداء الجل ، مثل سعة الانتفاخ ، و حقن PPG ، و كفاءة التوصيل ، بعناية. كما تم ذكر العوامل المؤثرة على تصميم برنامج الحقن و الاستخدامات الحقلية لـ PPG. و كذلك تمت الاشارة الى بعض الدراسات التجريبية على PPG.

الكلمات الدالة: بولي أكريلاميد ، هلام في الموقع ، هلام الجسيمات مسبقة التشكيل ، التحكم في المطابقة