

P-2019/52677

SUPERINTENDENCIA DE INDUSTRIA Y COMERCIO

DIRECCIÓN DE NUEVAS CREACIONES

E. S. D.

Re: Expediente No. **NC2019/0013619**

Solicitud de patente a nombre de **SIEMENS ENERGY INC.**

Yo, CAROLINA DAZA MONTALVO identificada como aparece al pie de mi firma, domiciliada en la Carrera 11 No. 86-53, obrando como apoderada de la sociedad SIEMENS ENERGY INC., domiciliada en Florida, Estados Unidos de América, solicitante de la patente de la referencia, en respuesta al oficio No. **16907**, notificado electrónicamente el 02 de noviembre de 2021, relacionado con los requerimientos de fondo de la solicitud, atentamente me permito presentar la siguiente información:

1. No se presenta Modificación a las Reivindicaciones

A este respecto, el solicitante desea manifestar respetuosamente que se reafirma en el capítulo reivindicatorio presentado el 26 de julio de 2021, conformado por veinte (20) reivindicaciones, por lo cual, no se presentan modificaciones a las reivindicaciones.

2. Pago de tasas

Atentamente nos permitimos decir que no se adjunta recibo por concepto de pago de tasa de modificaciones, toda vez que ni el capítulo reivindicatorio ni el capítulo descriptivo han sido modificados, según lo establecido en la Resolución No. **59669 de 2020**.

3. Claridad y concisión de las Reivindicaciones

El solicitante desea manifestar que el capítulo reivindicatorio previamente presentado proporciona claridad y concisión a la invención reclamada, y cuenta con pleno soporte en la descripción de la solicitud en estudio. En particular, frente a cada objeción, me permito señalar lo siguiente:

3.1 El examinador ha indicado *"Los términos 'al menos' (Reiv. 1, 12), 'o mayor' (Reiv. 3, 14) son relativos, por lo cual no definen ni delimitan adecuadamente el alcance de las reivindicaciones (...)"*. En este respecto, El solicitante desea manifestar su desacuerdo ya que los términos utilizados indican una cantidad mínima de polímero potenciador de la viscosidad que está presente en la corriente de alimentación. El término *"al menos"* no es un término relativo ya que no se compara con nada, sino que es una cantidad mínima. El solicitante también señala que el valor se mide en mg/L. Como entendería un experto en la técnica, esto significa "X" mg de polímero potenciador de la viscosidad por litro de la corriente de alimentación. Como tal, existe un límite superior natural para la cantidad de polímero potenciador de la viscosidad. Específicamente, la corriente de alimentación podría ser 100% de polímero potenciador de la viscosidad, pero no podría exceder ese valor.

Respecto a la expresión *"o más"* es simplemente una forma diferente de decir *"al menos"*. Ambas reivindicaciones son amplias, pero tienen un límite superior claro y, por lo tanto, delimitan claramente el alcance de las reivindicaciones. No son términos relativos, ya que no requieren una comparación con otra característica o componente, y se pueden medir fácilmente. Un tercero que desarrolle un proceso similar podría medir fácilmente esta cantidad para determinar si su proceso potencialmente infringe y comprendería fácilmente cómo evitar dicha infracción.

El examinador comentó los argumentos del solicitante relacionados con las frases *"al menos"* y *"o más"*. Es importante señalar que la afirmación del examinador de que estas frases *"no limitan el alcance de la solicitud ya que incluye todo el universo de valores que se encuentran por encima de la cantidad reclamada"* es incorrecta. Estos valores tienen límites superiores ya que se

describen como una porción de un litro de la corriente de alimentación. El límite superior sería que la corriente de alimentación sea 100% polímero potenciador de la viscosidad.

De acuerdo con lo anterior, el solicitante no puede encontrar una razón por la que estos términos se consideren indefinidos de ninguna manera y sostiene que estos términos son admisibles. Por lo cual, se solicita amablemente sean mantenidos dentro del pliego reivindicatorio.

3.2 El examinador ha establecido *"La reivindicación 1 pretende caracterizar el método por la composición de la corriente de alimentación, lo cual no es una manera aceptable de caracterizar el método ya que los métodos solo deben caracterizarse por sus etapas y/o las condiciones de las mismas. Se recomienda colocar la frase 'comprendiendo la corriente de alimentación (12) los hidrocarburos, una concentración de un polímero potenciador de la viscosidad de al menos 10 mg/L, y un fluido acuoso' como parte del preámbulo de la reivindicación"*. En este respecto, el término "corriente de alimentación" en ausencia de alguna definición tiene muy poco significado. Un flujo de agua, aire, una mezcla de fluidos, etc. pueden considerarse "corrientes de alimentación". El solicitante reconoce que el método mencionado en la reivindicación 1 no funcionará con ninguna corriente de alimentación posible. Por lo tanto, para mayor claridad, el solicitante ha definido de qué está compuesta la corriente de alimentación dentro de la reivindicación, en lugar de confiar simplemente en la descripción. Si una referencia de la técnica anterior menciona una corriente de alimentación que no cumple con estos requisitos mínimos, **no** es una "corriente de alimentación" como se indica en la presente invención.

A la luz de lo anterior, el lenguaje objetado por el examinador simplemente define el término "corriente de alimentación" y aporta claridad a la reivindicación. Como tal, el solicitante sostiene que el lenguaje es correcto y, por tanto, se solicita amablemente sea retirada dicha objeción.

3.3 El examinador ha indicado *"La frase 'que comprenden cada una, una mezcla de un producto de madera y una poliolefina' (Reiv. 1) carece de concisión, ya que no es posible establecer con precisión ni la composición ni la*

conformación de las partículas reclamadas (...)”. En este respecto, el solicitante desea manifestar respetuosamente su desacuerdo. Como cuestión inicial, el examinador no objetó el término “partículas de materiales compuestos”, por lo que no está claro cómo la provisión de una definición más limitada de ese término puede carecer de concisión. La concisión implica que el término no es claro o es demasiado amplio. Si el término es demasiado amplio, el examinador no debería tener problemas para proporcionar el estado de la técnica que requeriría reducir los términos. En cuanto a la claridad, el término debe ser comprensible para un experto en la materia para permitirle determinar si podría infringir o no. Un “producto de madera” simplemente requeriría partículas hechas de algún tipo de madera con varios ejemplos provistos en la descripción. El término “poliolefina” es un tipo de polímero bien definido. (Ver <https://en.wikipedia.org/wiki/Polyolefin>).

De acuerdo con lo anterior, el solicitante cree que estos términos no carecen de concisión y, de hecho, agregan una definición adicional al término partículas de materiales compuestos. Por tanto, se solicita amablemente retirar dicha objeción.

3.4 El examinador también se opone a una serie de frases que, según el examinador, sugieren resultados a alcanzar y argumenta que son inapropiadas ya que *“incluirían no solo la solución propuesta por el solicitante, sino todas las alternativas presentes o futuras que lleguen a ese resultado”*. En este respecto, el solicitante desea manifestar respetuosamente su desacuerdo con la conclusión del examinador con respecto a la amplitud de la cobertura de estas cláusulas. El solicitante reconoce que podrían cubrir otros procesos y sistemas futuros, pero solo si esos procesos y sistemas cumplen con las limitaciones específicas de la reivindicación 1 y específicamente si ponen en contacto la corriente de alimentación con las partículas de materiales compuestos específicas mencionadas en las reivindicaciones 1 y 12.

En consecuencia, nos permitimos indicar que el capítulo reivindicatorio previamente presentado, que incluye veinte (20) reivindicaciones, se ajusta a las disposiciones del artículo 30 de la Decisión 486/00.

4. Descripción

Con respecto a la objeción a la Descripción, el examinador plantea una objeción a la descripción, pero no está claro qué cambios específicos se solicitan. El examinador señala que algunos términos como polímero potenciador de la viscosidad, mezcla heterogénea y material a base de celulosa son ambiguos. Una persona con conocimientos ordinarios en la técnica de la producción de petróleo comprendería inmediatamente qué se entiende por polímero potenciador de la viscosidad y este término no requeriría una definición adicional. Sin embargo, la descripción incluye varios párrafos que definen además el polímero como "cualquier polímero que proporcione a la corriente de fluido 12 un mayor grado de viscosidad que la corriente de fluido sin el polímero que mejora la viscosidad y/o aumenta la movilidad de los hidrocarburos (aceite) en el depósito de petróleo subterráneo en el que se inyecta la corriente 12. El polímero puede ser cualquier material adecuado que produzca una o ambas de estas propiedades/efectos. Además, como se usa en este documento, el término "polímero" denota una cadena unida covalentemente de unidades monoméricas, y pretende incluir tanto homopolímeros como copolímeros". La descripción establece además que "una realización, el polímero comprende un polímero aniónico, que se cree que estabiliza las gotas de aceite debido a los efectos estéricos y de repulsión y, por lo tanto, dificulta la recuperación del aceite. El polímero aniónico puede comprender grupos funcionales aniónicos dentro de la propia cadena polimérica o añadidos a la cadena como grupos funcionales colgantes. En realizaciones específicas, el polímero aniónico puede comprender una poliacrilamida hidrolizada (HPAM)". De acuerdo con lo anterior el solicitante no tiene claro qué más se necesitaría.

Con respecto a los otros términos mencionados por el examinador, no están incluidos en las reivindicaciones, por lo que no está claro por qué se requeriría una mayor explicación.

A la luz de lo anterior, se solicita respetuosamente que se proporcionen objeciones específicas que se relacionen con las reivindicaciones para que puedan ser abordados adecuadamente. Por tanto, se solicita sea retirada dicha objeción

5. Nivel Inventivo

El examinador establece que las reivindicaciones 1 a 20 carecen de nivel inventivo a la luz de las enseñanzas descritas en el documento WO2012/119033 (D1).

A este respecto, me permito decir que el artículo 18 de la Decisión 486 establece que *“Se considerará que una invención tiene nivel inventivo, si para una persona del oficio normalmente versada en la materia técnica correspondiente, esa invención no hubiese resultado obvia ni se hubiese derivado de manera evidente del estado de la técnica”*.

Lo anterior significa que el análisis de nivel inventivo **NO** es una comparación de los objetos de las anterioridades y la solicitud en estudio. El análisis de nivel inventivo **debe demostrar** la obviedad de la invención y establecer cómo ésta no contiene un salto cualitativo, que demuestre su altura inventiva, teniendo en cuenta que se hace **necesario demostrar** que la invención analizada carece de nivel inventivo y hubiese sido obvia para una persona versada en la materia.

De acuerdo con lo anterior, el solicitante desea manifestar respetuosamente su desacuerdo, ya que las **características del capítulo reivindicatorio previamente presentado no se encuentran divulgadas o sugeridas en el documento citado por el examinador**. En consecuencia, las reivindicaciones actuales son novedosas e inventivas a la luz del estado del arte. Adicionalmente, el solicitante desea presentar los siguientes argumentos en contra de la objeción del examinador.

Como se discutió en los Antecedentes de la solicitud, se sabía que era muy difícil tratar adecuadamente el agua que incluye aceite y polímeros que mejoran la viscosidad. El documento adjunto a este memorial titulado “Challenges in Processing Produced Emulsion from Chemical Enhanced Oil Recovery - Polymer Flood Using Polyacrylamide” se publicó el 19 de julio de 2011 y se refiere específicamente a las dificultades en el tratamiento del agua creadas mediante el uso de un polímero potenciador de la viscosidad. *Ver Resumen y página 2, tercer párrafo, énfasis añadido.*

La página 3 de dicho documento incluye una sección que aborda específicamente las dificultades en el tratamiento del agua creadas por el uso de polímeros que potencian la viscosidad. Volviendo a la página 11, se analiza un ejemplo en el que se empleó una gran cantidad de polímero potenciador de la viscosidad. Sin embargo, el solicitante, a través de sus propias pruebas, determinó que un umbral mucho más bajo provoca desafíos en el tratamiento del agua.

Es importante destacar que la Fig. 6 del documento ilustra el efecto sobre la eliminación o separación de aceite para dos procesos con y sin un polímero potenciador de la viscosidad. Como puede verse, hay una disminución significativa en la eficacia de ambos procesos cuando se añade el polímero potenciador de la viscosidad.

A la vista de este documento, debe quedar claro que el problema resuelto por la presente invención era conocido y no resuelto, y que los resultados logrados utilizando el proceso y el sistema mencionados son inesperados dado el uso del polímero potenciador de la viscosidad.

Específicamente, también es bien conocido que, si se usa en cantidades superiores a 10 mg/L, es muy difícil separar el aceite del polímero potenciador de la viscosidad después de extraerlo.

Por lo tanto, la presente invención resuelve un problema que ha afectado a la industria durante algún tiempo. Además, el uso de polímeros potenciadores de la viscosidad en cantidades de 50 mg/L o mayores mejora aún más la extracción de aceite, pero también aumenta en gran medida la dificultad para separar el aceite extraído.

No hay ninguna enseñanza o sugerencia desde D1 que lleve a alguien con conocimientos ordinarios en la técnica a utilizar una combinación de un producto de madera y una poliolefina para separar el aceite y los otros componentes en la corriente, y mucho menos que este material pueda realizar con éxito la separación con polímeros potenciadores de la viscosidad en concentraciones superiores a 50 mg/L.

A la luz de lo anterior, el solicitante ha proporcionado un paso inventivo sobre D1. Como tal, las reivindicaciones 1-20 son admisibles.

De acuerdo con lo anterior y teniendo en cuenta que el documento D1 **no menciona, describe o sugiere de forma individual o en combinación,** todas las características técnicas reclamadas en el capítulo reivindicatorio previamente presentado, **dichas reivindicaciones son novedosas, e inventivas sobre el estado del arte.**

En este sentido, y siguiendo el Manual Andino de Patentes, la presente invención tal y como se encuentra definida en las reivindicaciones 1 a 20, tiene diferencias con el estado del arte e implicó un nivel inventivo durante su desarrollo, por lo cual debe ser considerada como novedosa e inventiva según las disposiciones de los artículos 14, 16 y 18 de la Decisión 486.

6. Conclusión

Con los argumentos presentados puede concluirse que:

- i) La presente solicitud es clara, concisa y está debidamente soportada en la descripción, cumpliendo con los requerimientos del Artículo 30 de la Decisión 486; y
- ii) Las reivindicaciones actuales son patentables sobre D1, cumpliendo así con los requerimientos del Artículo 18 de la Decisión 486.

Por tanto, atentamente me permito solicitar a ese Despacho otorgar el privilegio de patente solicitado a la solicitud en estudio, toda vez que cumple a cabalidad con los requerimientos de la Decisión 486/00.

En consecuencia, solicitamos a ese Despacho pronunciarse en relación con todos los argumentos presentados en este memorial dando estricta aplicación al principio del debido proceso consagrado en el artículo 29 de la Constitución Nacional.

7. Anexos

- Documento "Challenges in Processing Produced Emulsion from Chemical Enhanced Oil Recovery - Polymer Flood Using Polyacrylamide".

Señora Directora,



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ARTICLE NAVIGATION

Challenges in Processing Produced Emulsion from Chemical Enhanced Oil Recovery - Polymer Flood Using Polyacrylamide ☑

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Paper presented at the SPE Enhanced Oil Recovery Conference, Kuala Lumpur, Malaysia, July 2011.

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<https://doi.org/10.2118/144322-MS>

Published: July 19 2011

Abstract

Polymer flood using polyacrylamide is an effective way to increase oil production in many aged fields. While extensive research and development and field practices have demonstrated the improvements in oil recovery using this technology, the development on effective methods of processing the produced emulsion from polymer flood lags behind. The polymer in the injection fluid, which alters its physical and chemical behaviors, ultimately breaks out with the produced emulsion and changes its physical and chemical characteristics. This leads to tighter emulsions, increased produced water viscosities, stronger chemical interactions, limitations on the processing methods and process conditions, reduced efficiency on current equipment technologies, and even excessive equipment failures and damages. Adding to the processing difficulties is the uncertainty of the break out fluids. As polymer passes through reservoirs, its physical and chemical properties change due to formation absorption, shearing, and chemical reactions. As a result, the produced polymer is different from the injected polymer, and constantly changing during the production cycle. This requires the emulsion processing technologies to be flexible and stable throughout a large operation envelop.

Keywords: upstream oil & gas, cloudiness, continuous heating, enhanced recovery, emulsion, hydrocyclone, produced water discharge, viscosity, producer, polymer flood

Subjects: Improved and Enhanced Recovery, Environment, Chemical flooding methods, Water use, produced water discharge and disposal

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Introduction

As a method of chemical enhanced oil recovery (EOR), polymer flood using polyacrylamide has been proven to be an effective approach to increase oil production in many aged oil fields both

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in lab testing and field practices. More oil producers are actively evaluating polymer flood as a viable production method to increase recoverable reserves. Commercial practices are also underway in several areas around the world.

Polymer flood offers the benefit of simple and cost effective injection system setup, and relatively low operating cost comparing to other EOR methods. Polymer flood is effective to increase oil production over a wide range of oil reservoir conditions. Currently, polymer flood has been conducted in large scale in China for light to medium oils and Canada in medium to heavy oils.

While polymer flood is effective in increasing oil production, it seriously impacts produced emulsion processing. The polymer in the injection fluid ultimately breaks out with the produced emulsion and changes its physical and chemical characteristics. Changes in physical and chemical properties include tight emulsions, increased viscosities, and strong chemical interactions. The impact on production methods includes limitations on the processing methods and process conditions, reduced efficiency on current equipment technologies, and even excessive equipment damages.

Due to the concern of environment impact caused by discharging polyacrylamide with produced water, producers using polymer flood prefer reusing the produced water by blending fresh polymer into the treated produced water. However, the requirements for the injection water as determined by the reservoir engineering and the reservoir conditions are, in many cases, more restrictive on the residual oil content in water than the discharge limits set by the environment protection regulations.

Common Emulsion Processing Problems

Equipment Failures and Damages.

Operators currently practicing polymer flood using polyacrylamide have experienced significantly increased failures in heating equipment, including heat exchangers and in-vessel heating elements such as firetubes. Heat exchangers suffer severe fouling. In some cases, the outlet temperatures of heat exchangers show measurable decreases on a daily basis. Firetubes can be even worse. In some cases, after converting a water flood process to polymer flood, the fouling rate can increase by more than 10 times after the polymer break through. The damaged firetubes all show severe deposits which cause excessive high temperatures on the firetubes resulting in firetube collapse

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Limited Temperature Range.

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The heat exchanger failures or firetube damages are escalated at higher process temperatures.

However, in general, increased temperature improves emulsion separation, and higher temperature is especially desirable for heavy oil processing. The significantly increased heat exchanger failures or firetube damages limit the benefit polymer flood technology can achieve on heavy oil.

Water Treatment Difficulties.

Water treatment difficulties are more obvious in the advanced treatment equipment such as hydrocyclones and gas flotation units (IGF). As polyacrylamide introduces high viscosity and strong chemical interactions into the produced fluids, the performances of hydrocyclones and IGFs suffer dramatically. Currently, using skimming tanks with high retention time is a common practice.

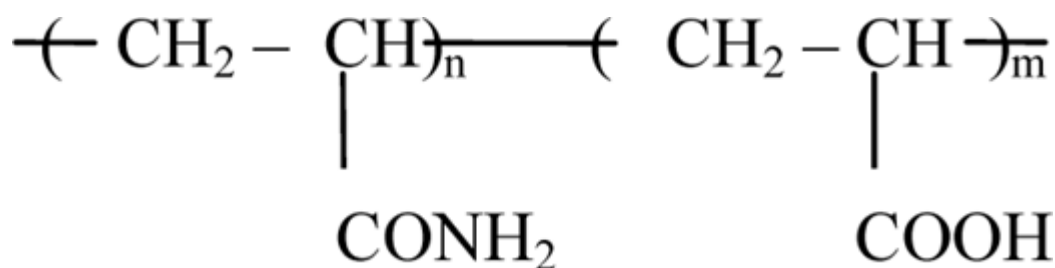
Processing Chemicals and Their Dosages.

Due to the chemical activities caused by break through polyacrylamide, new chemicals need to be developed specifically for polymer flood. These chemicals should have no negative interaction with polymer while being effective in destabilizing the polymer laden emulsion. The chemical dosages can be much higher comparing to water flood which result in higher operating cost.

Analysis and Discussions on the Emulsion Processing Problems

The Basic Characteristics of Partially Hydrolyzed Polyacrylamide.

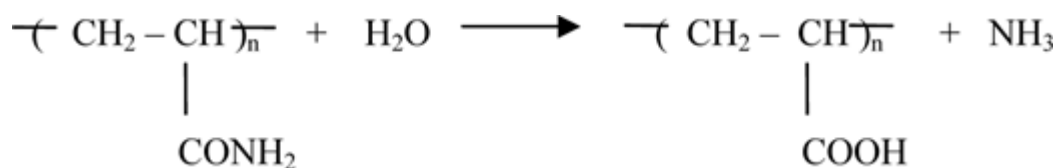
The partially hydrolyzed polyacrylamide (HPAM) used in polymer flood is a copolymer of acrylamide and acrylic acid. Its molecular formula is as follows:


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As HPAM passes through the reservoir, process lines and equipment, it is subjected to mechanical shearing, free radical degradation, hydrolysis reaction, formation absorption, among other physical and chemical effects. Comparing to the injected HPAM, the produced HPAM shows lower molecular weight and a higher degree of hydrolysis (You *et al.* 2007) which gives it stronger anionic characteristics.

Mechanical shearing and free radical degradation break down the HPAM polymer chain and reduce its molecular weight. Mechanical shearing and free radical degradation are not totally independent of each other (Rho *et al.* 1996) as shearing can introduce free radicals to initiate the free radical degradation. While polymer chain break down can be reduced by oxygen scavengers such as NaHSO₃ and antioxidants such as thiourea and IPA, it cannot be totally eliminated in field practices. Field data shows a significant molecular weight reduction in the produced polymer compared to injected polymer (You *et al.* 2007).

The hydrolysis reaction converts the amide group to carboxylic acid by reacting with water. The hydrolysis reaction can be illustrated as follows:


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The rate of the hydrolysis reaction is directly related to temperature and pH. The carboxylic acid group is the contributor of the anionicity for HPAM. Hydrolysis reaction increases the carboxylic acid group, thus enhance the anionic characteristics of HPAM.

Anionic HPAM readily interacts with the cationic species which are present in the reservoir or introduced during production and surface processing. This interaction could be the main contributor, besides increased viscosities, for many issues that producers are experiencing at this time.

It is well documented that HPAM solution turns cloudy by water hardness cations (Moradi-Araghi, *et al.* 1987). This cloudiness is affected by the temperature, pH, the concentrations and types of water hardness cations, the concentration of HPAM, and degree of hydrolysis of HPAM. However, most of these studies were focused on the effect of polymer cloudiness on injection.

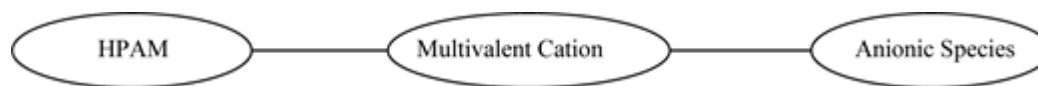
Its impact on the produced fluid processing has not been sufficiently investigated.

HPAM can easily form precipitates with trivalent cations such as Al³⁺ or Fe³⁺.

HPAM is commonly used as an effective anionic flocculant to precipitate cationic species.

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However, with the presence of multivalent cations, HPAM can also interact with anionic species through a cation bridging mechanism to form precipitates as illustrated in the following:

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In other words, under the right conditions, HPAM interacts with both cationic and anionic components. The interaction tends to accelerate at elevated temperature, and leads to accelerated cloudiness or precipitation.

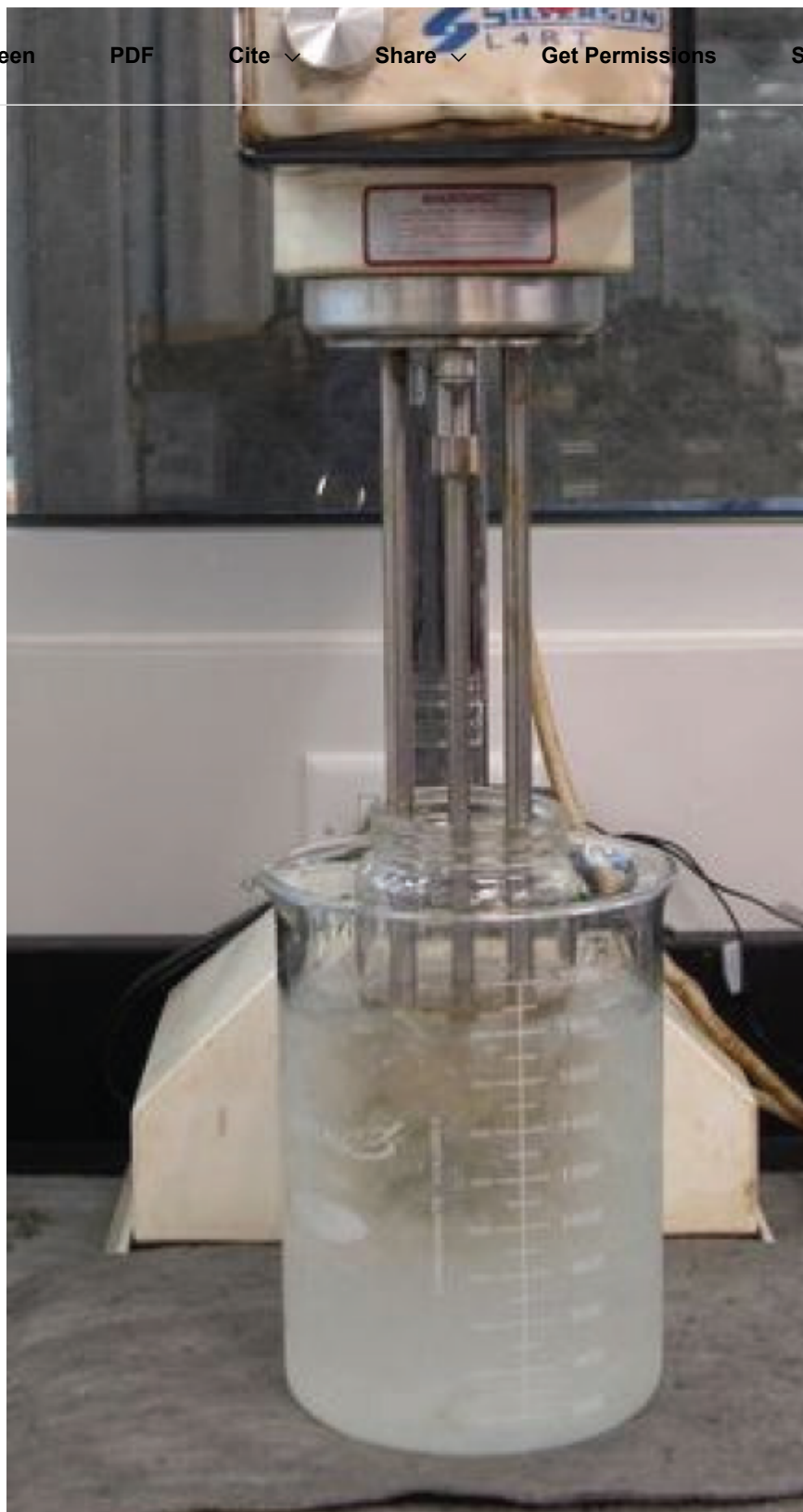
To further understand the HPAM cloudiness and precipitation, a polymer solution with 1000 mg/l of Floppam 3630S, 5200 mg/l total dissolved solids (TDS) and 40 mg/l total of Ca^{2+} and Mg^{2+} was tested in two different setups. The first setup was to test the HPAM cloudiness under mechanical shearing. The second was to test the HPAM cloudiness under continuous heating and recirculation.

For the mechanical shearing test, the HPAM solution was stirred in a beaker under strong agitation for 1 hour using a Silverson L4RT mixer at different speed settings in the range of 5000 to 10000 rpm. A picture of the setup is in Figure 1. To limit the temperature of the polymer solution, the polymer solution container was submerged in icy water to maintain the temperature below 50°C during stirring. At the end of stirring, samples were observed for their cloudiness and precipitations.

Figure 1



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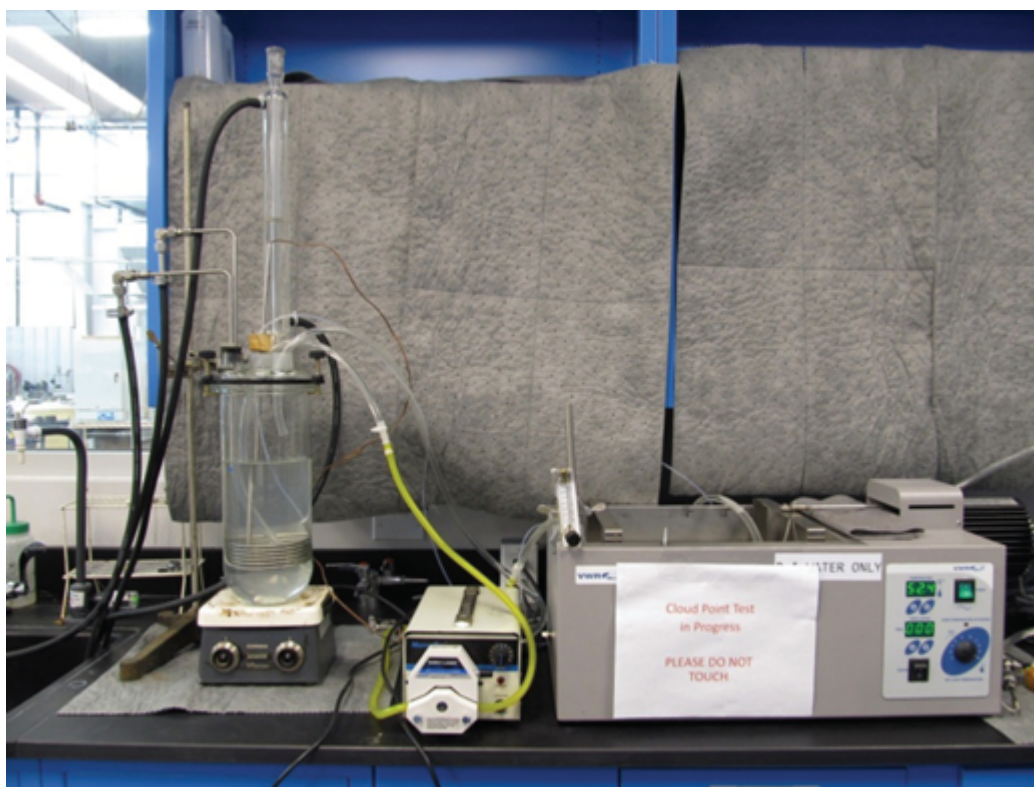
[Skip to Main Content](#) The cloudiness of polymer solution under shear mixing

The results indicated that all samples turned cloudy regardless the speed of the mixer within that speed range. The viscosity of the polymer solution decreased by 40% to 60% after shearing,

depending on the mixing speed, indicating polymer chain break down. Powdery precipitation was observed at the bottom of the beakers containing sheared polymer solution samples after setting overnight, and the solution turned clearer. The powdery precipitation did not dissolve back into the solution over time.

In the continuous heating and recirculation test, the HPAM solution was continuously circulated through a heating coil which was submerged in a water bath at different temperatures from 50°C to 97°C. A picture of the setup is in Figure 2. The polymer solution was continuous circulated and heated by the heating coil to temperatures from 46°C to 93°C. The cloudiness and precipitation in the polymer solution were observed during the tests.

Figure 2



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Testing setup for the cloudiness of polymer solution under continuous heating and circulation

The results showed that the polymer solution turned almost opaque under all testing

temperature conditions. A layer of deposit was observed on the tubing wall of the test setup. A

picture of the polymer solution before and after the continuous heating and recirculation test is

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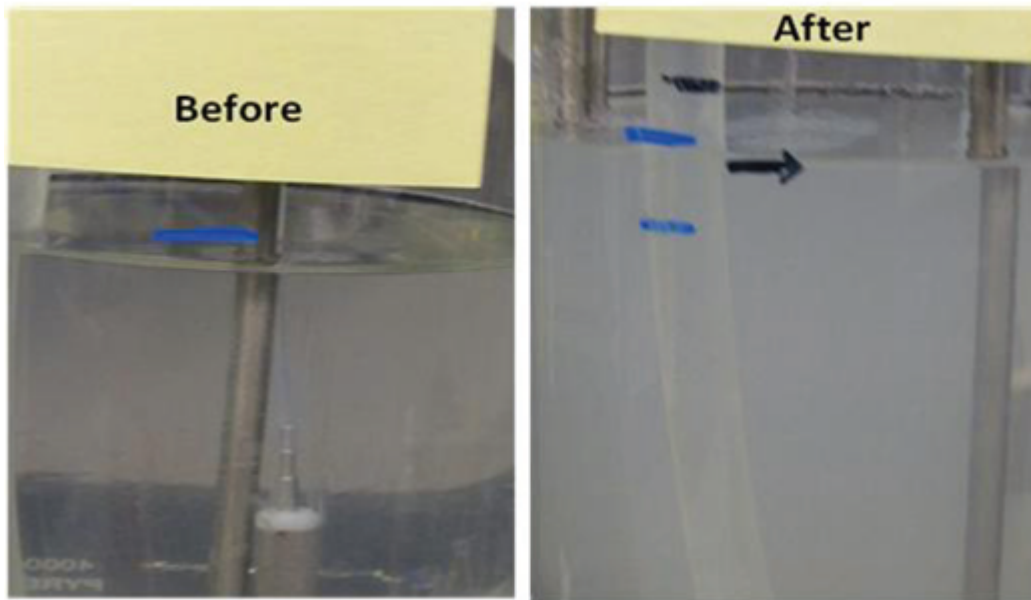
in Figure 3. A picture of the tubing before and after testing is in Figure 4. The higher the

temperature, the fast the polymer solution turned opaque. Even at 46°C, the polymer solution

turned opaque after 16 hours of continuous heating and recirculation. The results indicated that,

with sufficient mixing and time, polymer cloudiness can be observed at temperatures far below what has been reported by literature. This result is consistent with many field observations at the produced emulsion separation facilities.

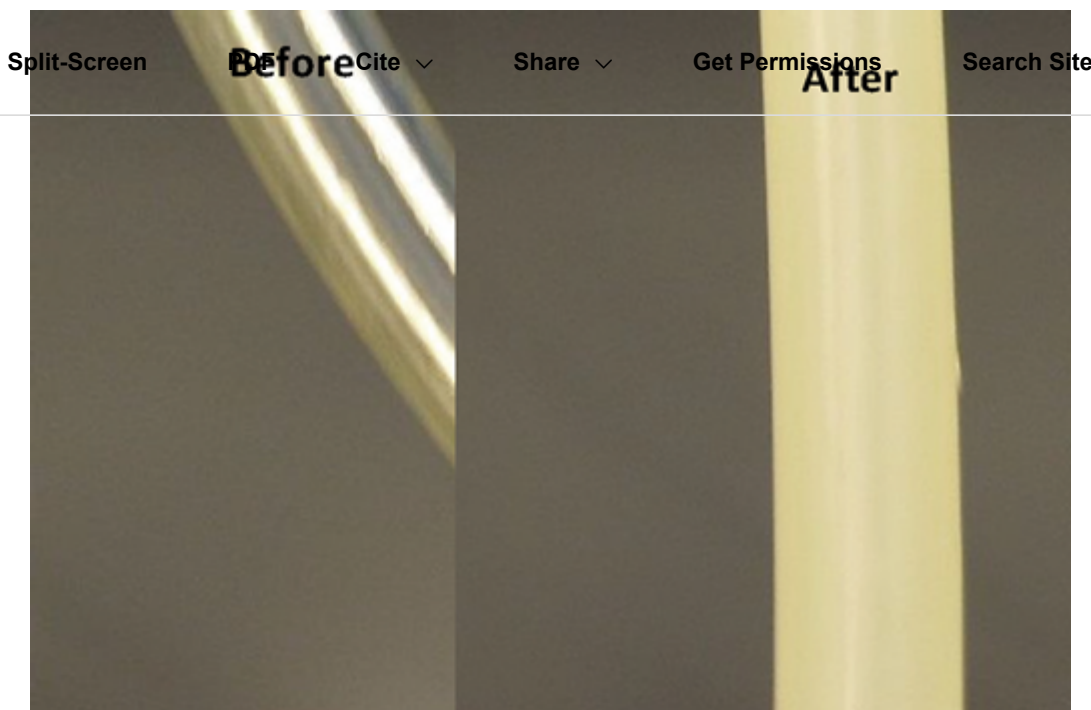
Figure 3

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Polymer solution before and after continuous heating and circulation

Figure 4

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Tubing in the test setup before and after continuous heating and recirculation

The opaque samples created from the continuous heating and recirculation test remained just as opaque after setting for 2 months. There was no precipitation on the bottoms of the sample containers. This suggests that the cloudiness formed in the continuous heating and recirculation test could be different from the cloudiness formed in the mechanical shearing test. Testing with polymer solutions without water hardness cation failed to produce cloudiness in either test setups. In the continuous heating and circulation test without water hardness cations, no cloudiness could be observed even when the polymer solution was continuously heated and recirculated at 93°C for 16 hours. This suggests that no matter the cloudiness precipitates or not, it involves water hardness cations. This is consistent with what has been reported in literature. However, the temperatures at which the cloudiness was observed was far lower than what have been reported. The non-precipitation and irreversible nature of the cloudiness created by the continuous heating and recirculation test has not been reported. The importance of these observations is not limited to the interaction between HPAM and water hardness cations. They revealed the chemical activity caused by the anionicity of the HPAM. The increased degree of hydrolysis in the break through HPAM will only enhance that chemical activity. Multivalent cations can bond with the carboxylic groups within a single HPAM molecule or among multiple HPAM molecules. When a multivalent cation interacts with the carboxylic groups in a single HPAM molecule, it curls the HPAM and reduces its capability of combining with water. When a multivalent cation interacts with the carboxylic groups in different HPAM

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molecules, it creates ionic crosslinking. Molecules with multiple cationic functional groups can interact with HPAM just like the multivalent cations.

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Produced Fluid Process Design and Engineering.

Currently, the majority of the fields that are practicing polymer flood using HPAM were converted from water flood. During the conversion, the producers mainly focused on the polymer blending, injection, maintaining the polymer viscosity, etc. Very little attention was given to the changing behavior of the produced emulsion due to HPAM break through. In most cases, the process for the produced fluid treatment remained unchanged after converting water flood to polymer flood.

As polymer breaks out in the processing facility, operators experience significantly increased processing difficulties. Two problems are most common: heating equipment failures and water treatment issues.

Heating Equipment Failures.

In produced emulsion separation, two categories of heating equipment are commonly used, heat exchangers and in-vessel heating elements such as firetubes.

Many different types of heat changers have been proven effective in water flood applications. However, heat changers can easily foul in HPAM flood. As discussed above, HPAM brings chemical activities and can interact with many components in many different ways. These interactions can result in precipitations causing heat exchanger fouling. However, there is lack of a systematic understanding of the exact contributors to the precipitations and how to control the precipitations. The understanding and development of heat exchanger designs suitable for HPAM flood are far from sufficient.

When precipitations deposit on firetubes, they creates hot spots and can eventually lead to equipment damage. Unlike typical heat exchangers which provide large heat transfer surface areas and high heat transfer coefficients, firetubes depend on large temperature difference between hot and cold sides. Firetubes are typically installed directly in the process vessels and submerged in the process fluids which move at very low velocities resulting in very low heat transfer coefficients. Therefore, the surface temperature of firetubes and the temperature gradient at the boundary layer of the firetubes are high even though the temperature of the bulk fluid is not. This localized hot zone around the firetubes can create an ideal environment

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to accelerate the chemical kinetics of HPAM, causing precipitation and deposits on the firetubes which create hot spot and eventually collapse the firetubes.

Analysis of the deposit has been conducted on a few failed firetubes from a HPAM flood producer. The results revealed a significant amount of amide groups which is a clear indication of HPAM in that deposit (Wylde *et al.* 2011).

HPAM related firetube damages have been brought up repetitively in discussions with producers, but not well documented in literature. The situation is quite severe among the heavy oil producers practicing HPAM flooding. Heavy oil needs high temperature for oil dehydration. However, the elevated fluid temperature expands the hot zone and further accelerates the HPAM related precipitation and deposition.

Water Treatment Difficulties.

Water treatment is critical in oil production. Numerous field experiences have shown that the presence of HPAM in produced water negatively impact the produced water treatment. In addition to the treatment difficulties, polymer flood producers are generally in favor of produced water reuse compared to produced water discharge. Depending on reservoir characteristics, injection requirements may demand better water quality, especially lower oil-in-water content, than discharge limits set by regulations.

Cameron conducted a systematic study on the effect of HPAM in hydrocyclones and IGF using Cameron's Oil Water Separation Flow Loop (OWS) which is a closed loop system for the development and testing of separation equipment. A picture of the OWS flow loop is in Figure 5.

Figure 5



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Cameron's Oil Water Separation (OWS) Flow Loop

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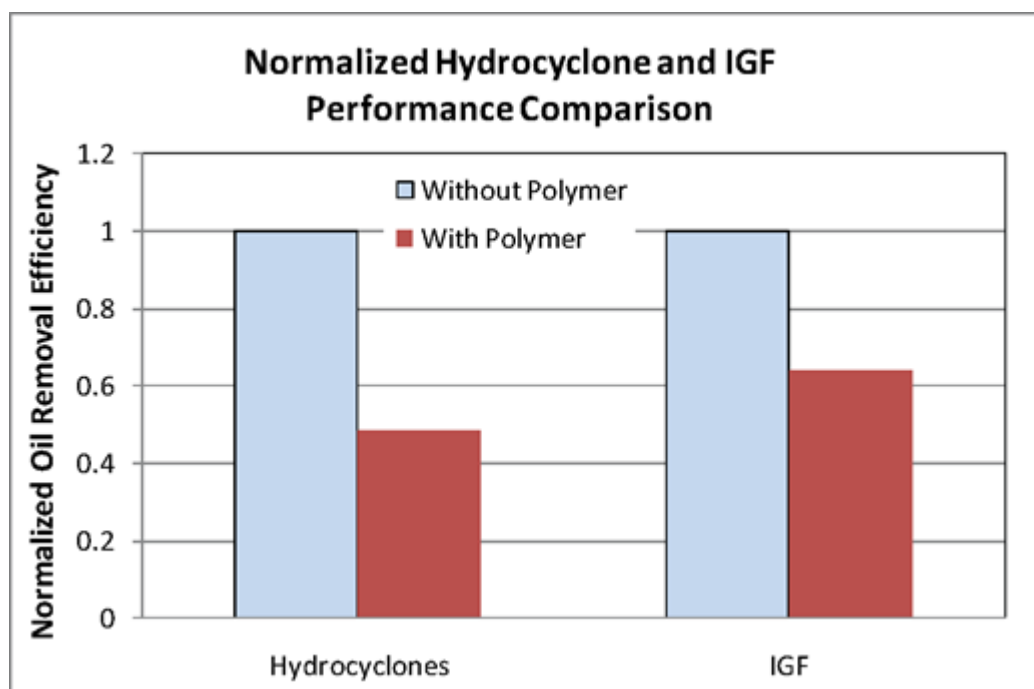
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Commercial sized hydrocyclones and IGF were investigated in the study. The study used an API

17° crude oil, and a synthetic polymer flood produced water with a TDS of 53000 ppm and polymer concentration of 1300 mg/L. Comparing performance using produced water with and without HPAM, the study showed a significant reduction in the water treatment efficiency for both hydrocyclones and IGF when HPAM was present. The normalized performance comparison with and without HPAM for hydrocyclones and IGF are illustrated in Figure 6.

Figure 6



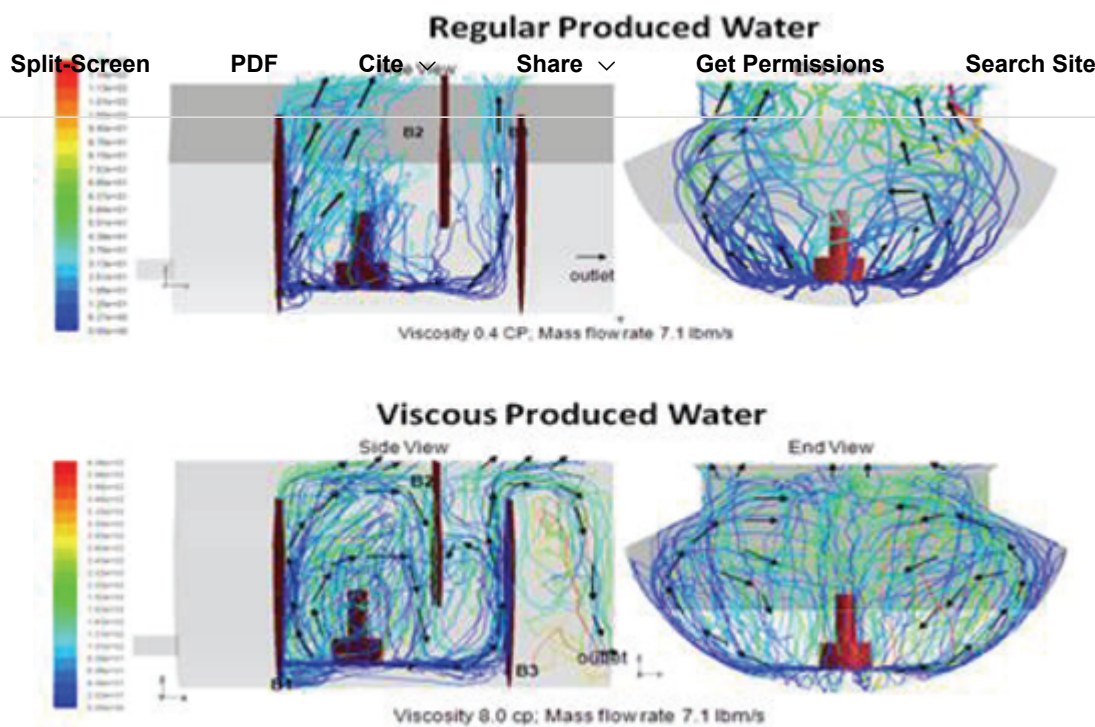
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The impact of HPAM on the oil removal efficiency of hydrocyclones and IGF

Research showed that the water viscosity impacts the performance of hydrocyclones and IGF significantly (Khan *et al.* 2009; Wang *et al.* 1999). Khan *et al.* (2009) conducted a Computational Fluid Dynamics (CFD) analysis for a single cell inside a 4-cell IGF to trace the trajectories of gas particles with regular produced water and viscous produced water. Their results are illustrated in Figure 7.

Figure 7
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Comparison of gas particle trajectories in an IGF cell in regular produced water and viscous produced water (Khan *et al.* 2009)

The study by Khan *et al.* (2009) revealed that, with viscous water, a large portion of the gas bubbles would be carried to the water outlet instead of floating to the top of the IGF cell. Significant flow short circuiting was caused by increased water viscosities. Even a 30% reduction of viscous water flow rate showed no effect on gas bubble separation.

Although equipment like hydrocyclones can be designed to accommodate increased viscosities, the uncertainty and ever changing nature of break through HPAM makes the viscosity hard to predict and constantly varying.

Adding to the viscosity is the chemical activities of HPAM. In oil field produced water treatment, cationic chemicals are commonly used because the dispersed oil in water tends to show anionicity. However, with the presence of break through HPAM, the anionic oil droplets are dispersed in an anionic HPAM solution. The cationic water treatment chemicals will have high interaction with HPAM. This not only reduces or even eliminates the effectiveness of cationic water treatment chemicals on dispersed oil, but may also cause undesirable side effects such as deposit or precipitations.

Overall, effective produced water treatment is challenging but crucial for HPAM flood. Current technology is not adequate. New technology is necessary. Effective produced water treatment

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technology is even more critical for the producers who desire to move polymer flood offshore. For offshore operation, cumbersome tanks with high retention time will not be cost effective.

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Conclusion

While polymer flood using polyacrylamide provides great opportunities in increasing oil production, it creates new challenges. The existing emulsion separation technologies do not provide effective solutions for the produced emulsions separation from polymer flood. New technologies are necessary. Currently, there is lack of a thorough and systematic understanding of the impact of break through HPAM. It will be beneficial if the industry takes a collaborate approach to address the issue of emulsion processing for polymer flood with polyacrylamide. This paper was selected for presentation by an SPE program committee following review of information contained in an abstract submitted by the author(s). Contents of the paper have not been reviewed by the Society of Petroleum Engineers and are subject to correction by the author(s). The material does not necessarily reflect any position of the Society of Petroleum Engineers, its officers, or members. Electronic reproduction, distribution, or storage of any part of this paper without the written consent of the Society of Petroleum Engineers is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of SPE copyright.

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