

# Polymers

for Enhanced Oil  
Recovery



 **BASF**

We create chemistry

# Make your EOR operations more economic with Aspiro™ Polymers

Mobility control is one of the most important concepts in any enhanced oil recovery process. Polymers are added to the water phase to increase its viscosity and reduce water permeability and thus decrease its mobility. To choose the best polymer for your conditions several factors have to be taken into account:

- ➊ Reservoir permeability and oil viscosity largely determine the choice in molecular weight of a suitable polymer.
- ➋ Reservoir temperature and brine composition have major influence on polymer stability and solubility under given conditions.
- ➌ Polymer injectivity, propagation profile, and retention behavior need to be considered to identify the most efficient solutions for your field.

## The Aspiro™ Polymer product range

BASF offers a variety of different Aspiro™ Polymers which can be used to match diverse crude oils and particularly diverse field conditions.

Aspiro™ Polymer	Type	Monomer Components	Application
P 42XX range	Copolymer	Acrylamide-Sodium Acrylate	T < 80 °C; low salinity; medium hardness
P 54XX range	Copolymer	Acrylamide – ATBS*	T < 95 °C; all salinities
P 66XX range	Associative Polymer	Acrylamide – ATBS* – Hydrophobic Monomer	T < 95 °C; all salinities; high resistance factor in reservoir esp. in high salinity, high temp. conditions
P 62XX range	Associative Polymer	Acrylamide – Sodium Acrylate – Hydrophobic Monomer	T < 80 °C; low salinity; high resistance factor

\* ATBS: 2-Acrylamido-tertiary-butyl sulfonic acid



### Standard

Aspiro™ P 4211

Aspiro™ P 4231

Aspiro™ P 4251

Aspiro™ P 4261

### Sulfonated

Aspiro™ P 5411

Aspiro™ P 5441 X

Aspiro™ P 5421

Aspiro™ P 5451 X

### Associative

Aspiro™ P 6631

Aspiro™ P 6201

Standard hydrolyzed polyacrylamide (HPAM) is the most widely used polymer in enhanced oil recovery applications. HPAM can be obtained either by post hydrolysis of acrylamide homopolymers or by copolymerization of acrylamide and sodium acrylate. Advantages and disadvantages of the different products are summarized here.



### Standard

#### Advantages

#### Disadvantages

### Posthydrolyzed PAM

High molecular weight;  
High viscosifying power

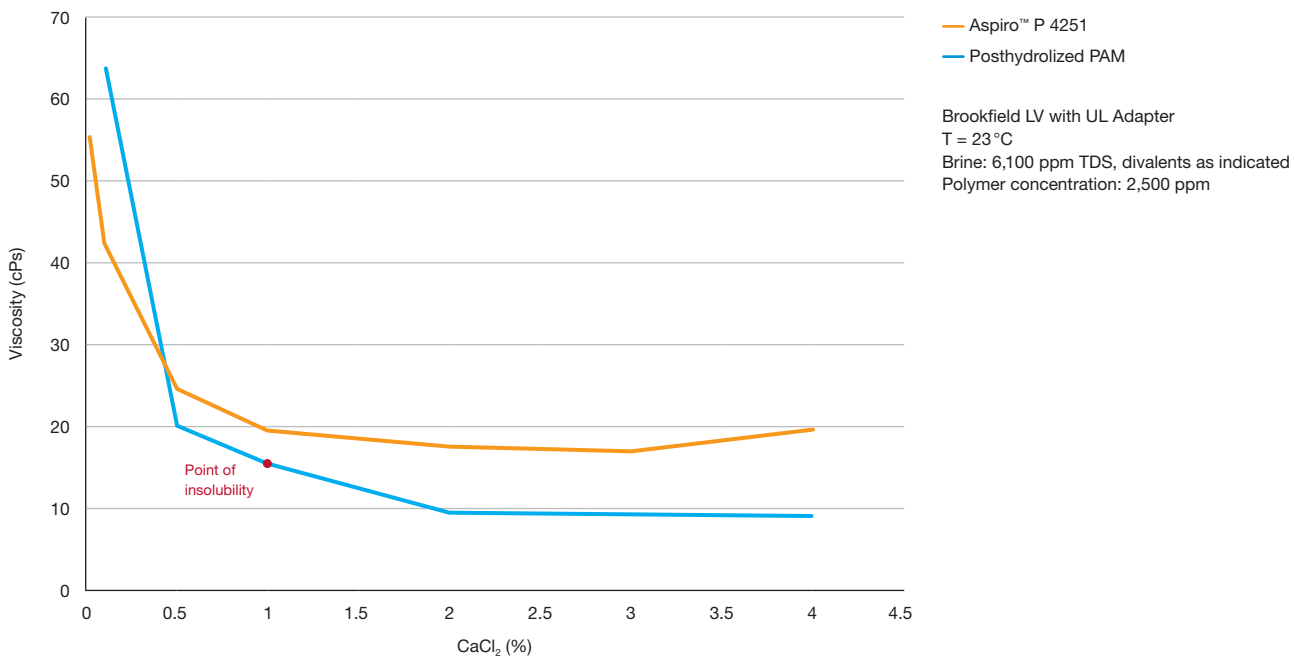
Low calcium tolerance;  
Shear sensitive

### Copolymer

Better calcium tolerance;  
Improved shear stability;  
Improved dissolution

Lower viscosifying power

Fig. 1: **Bulk viscosity of HPAM is strongly influenced by divalent ions**



BASF offers a range of copolymers that have a more narrow molecular weight and anionicity distribution as well as excellent solubility (e.g. Aspiro™ P 4251). For copolymers, anionicity in general has a strong impact on the overall solubility and adsorption performance of the polymer.

While high anionicity is advantageous to achieve low adsorption on sandstone rock, the solubility of the polymer is impaired in particular in saline brines.

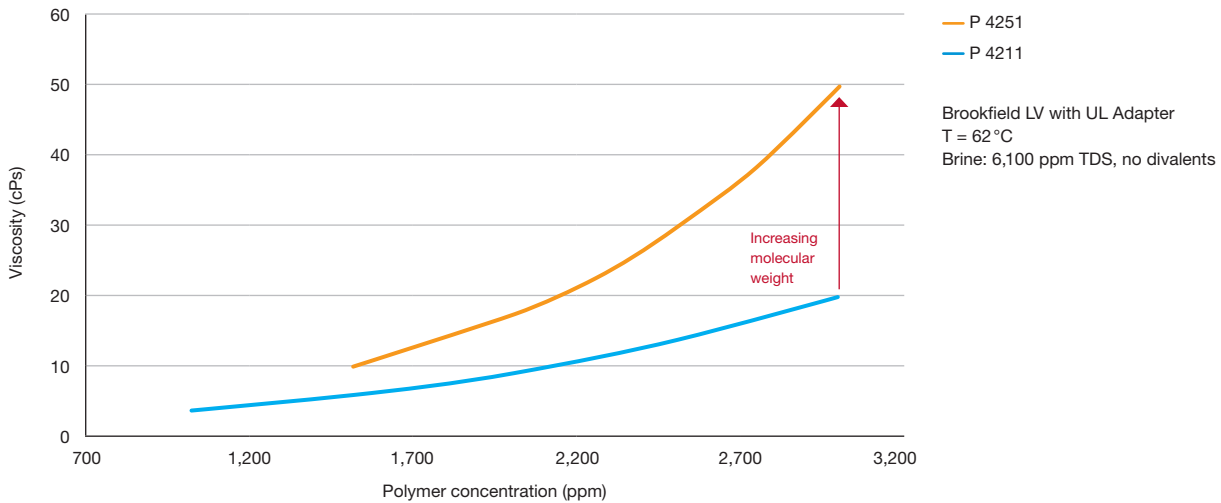
With increasing temperature lower anionicity products should be chosen since hydrolysis of acrylamide moieties will increase anionicity further. This, however, might cause precipitation when the polymer propagates in the reservoir.

The viscosifying power of a copolymer is mainly impacted by the molecular weight of the polymer. High molecular weights result in high viscosifying power. However, this results in a pronounced susceptibility against mechanical degradation.

Taking the different product requirements into account the Aspiro™ Polymer range covers different anionicities and molecular weights for varying field conditions with the viscosifying performance being shown in Fig. 2–5.



Fig. 2: Influence of molecular weight on bulk viscosity



Aspiro™ P 4251 exhibits a good viscosity performance at relatively low concentrations (Fig. 2). Viscosity remains constant even when calcium content is increased substantially (Fig. 3). This versatile applicable polymer is able to cover a wide range of salinities and temperatures while maintaining good solubility (Fig. 3 and 4).

Fig. 3: Influence of anionicity on bulk viscosity in presence of divalent ions

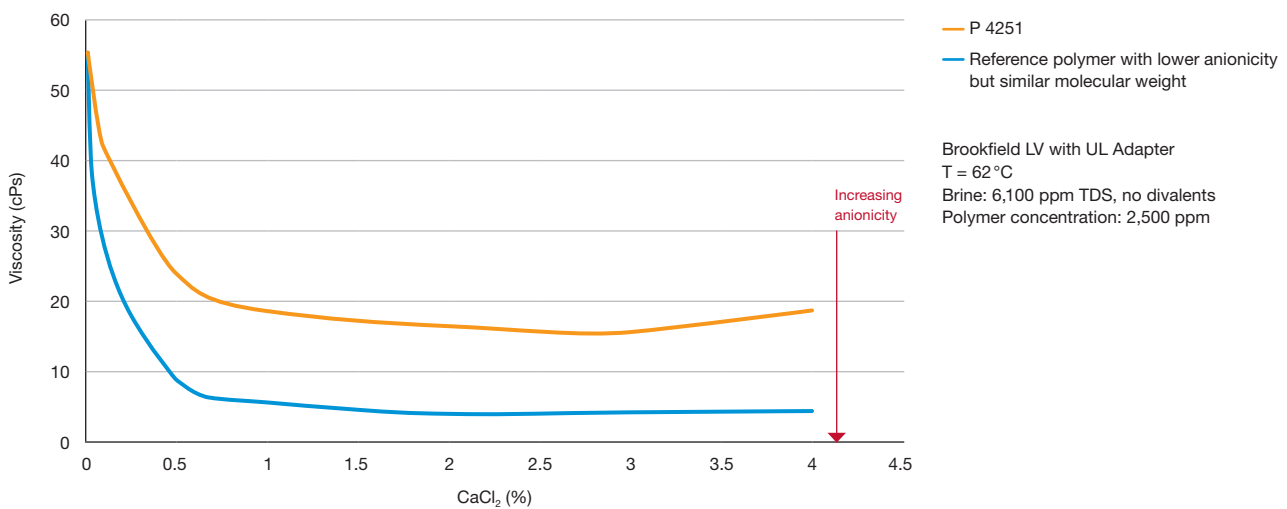


Fig. 4: Bulk viscosity scan of Aspiro™ P 4251 at 20 °C in brines with different salinities

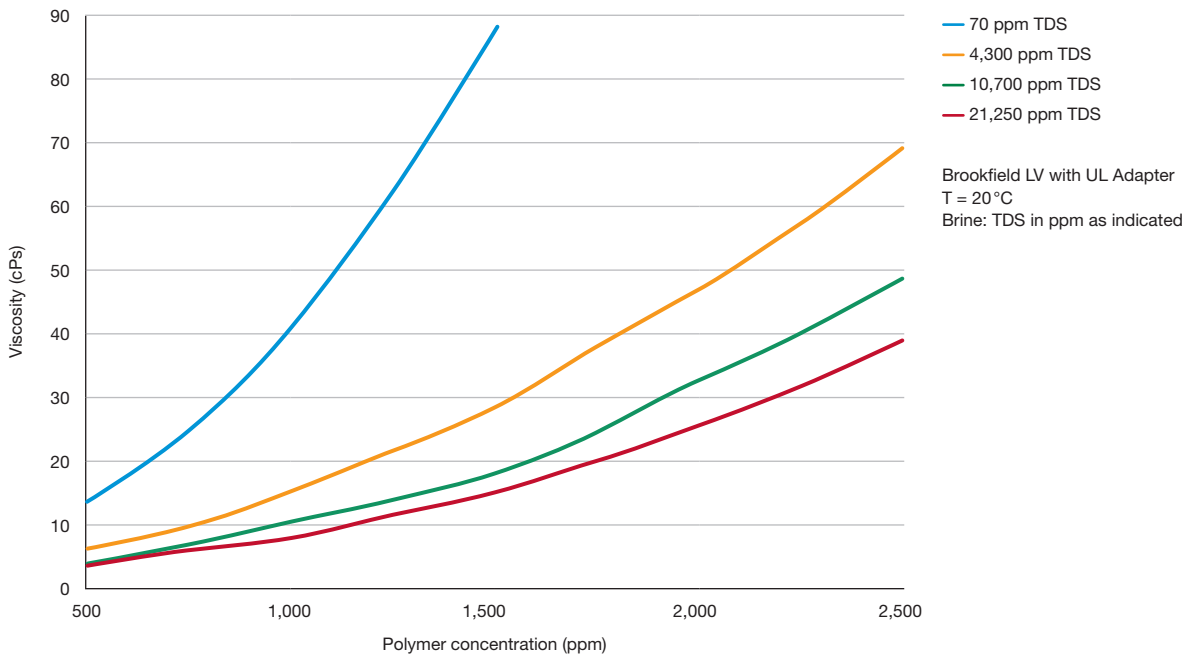
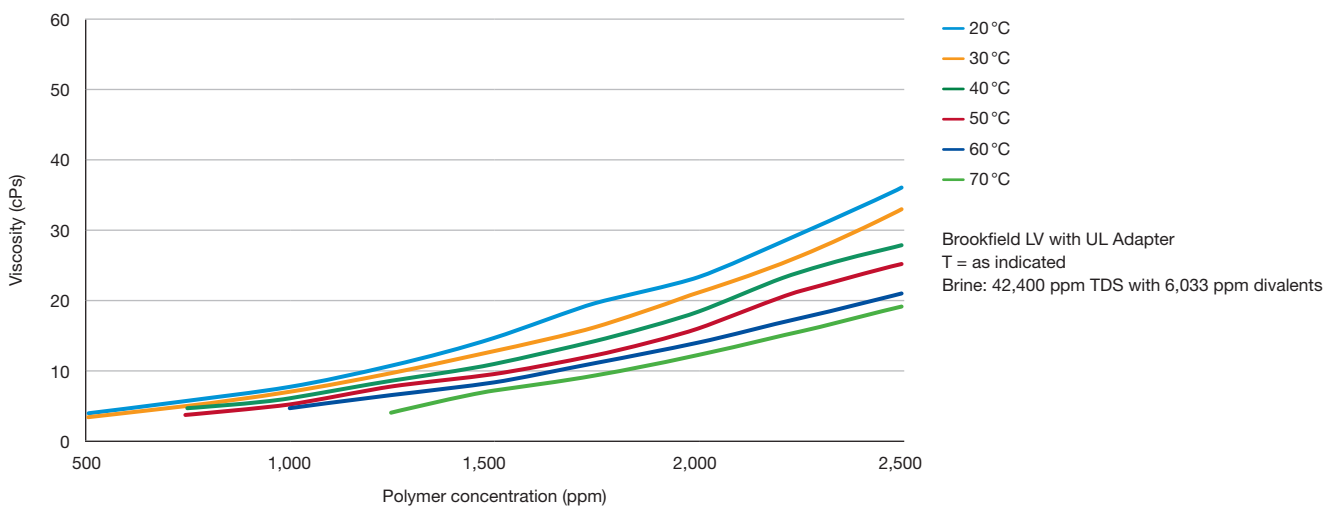


Fig. 5: Bulk viscosity scan of Aspiro™ P 4251 in a saline brine at different temperatures



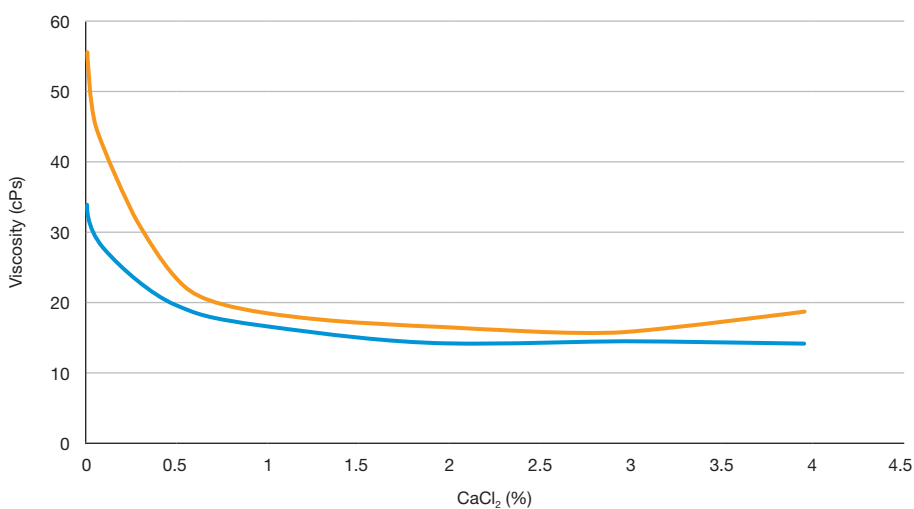
# High salinity conditions

When long term stability in highly saline brines at moderate to high temperatures is required, the stability of standard polyacrylamide sodium acrylate copolymers (Aspiro™ P 42XX series) against hydrolysis and degradation might not be sufficient. In this case BASF offers the range of sulfonated polymers (Aspiro™ P 54XX).

This polymer class is known to be less sensitive to high temperature, high salinity conditions. Fig. 6. depicts an improved viscosity performance of Aspiro™ P 5411 in the presence of divalent ions. While standard HPAM loses 69% in viscosity with increasing content of calcium ions, the more stable Aspiro™ P 5411 loses only 56% in viscosity. It is worth noting that the molecular weight of Aspiro™ P 5411 is lower than that of Aspiro™ P 4251.



Fig. 6: **Improved viscosifying stability of sulfonated HPAM in presence of divalent ions**



— P 4251  
— P 5411

Brookfield LV with UL Adapter

T = 62 °C

Brine: 6,100 ppm TDS, divalents as indicated

Polymer concentration: 2,500 ppm

# Associative polymers

**We support you to be more successful with our associative polymer technology.**

BASF has developed another range of commercial polymers based on associative technology which offers several application improvements over standard HPAM:

- 🕒 significantly lower polymer consumption
- 🕒 excellent mobility control
- 🕒 improved sweep efficiency

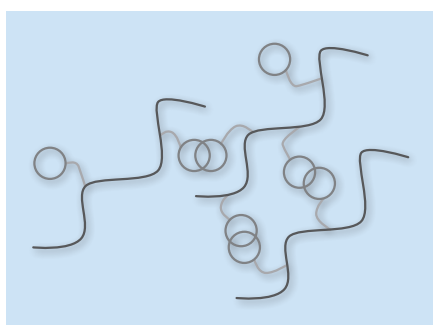
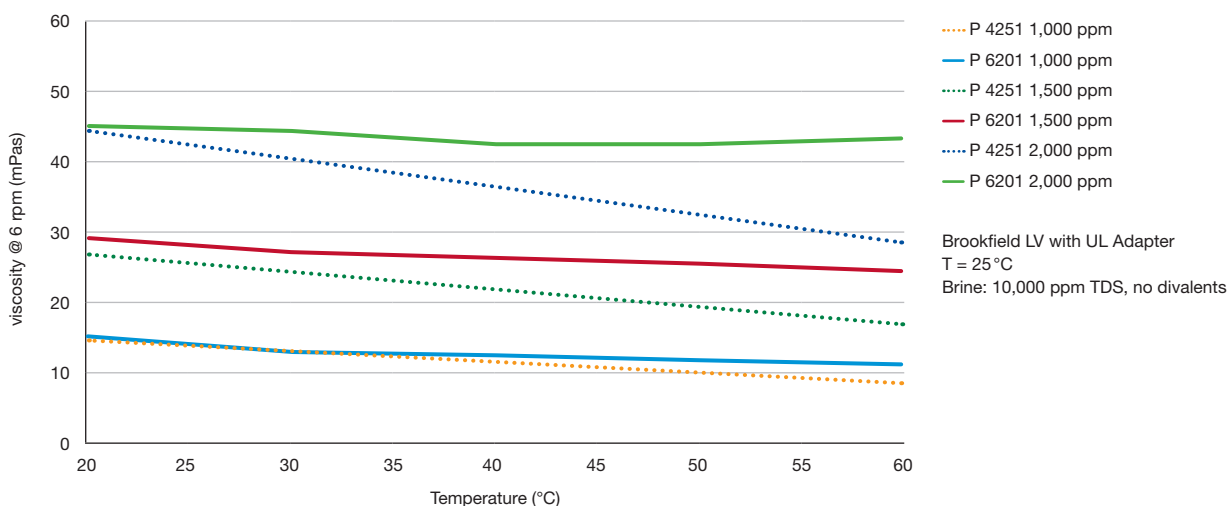


Fig. 7: Sketch of polymer network formed by associative polymers

Associative polymers are hydrophobically modified, but still water soluble polymers. Compared to standard HPAM, small amounts of hydrophobic groups are incorporated in the polymer backbone in addition to the well known monomer components acrylamide and sodium acrylate. The hydrophobic side groups of different polymer molecules interact with each other and thereby generate additional viscosity by forming a polymer network (see Fig. 7). Since the viscosity of this polymer network is significantly larger than that of independent, individual polymer chains, associative polymers in general are able to deliver superior viscosifying power than standard HPAM of a similar molecular weight.

All Aspiro™ P 6XXX associative polymers have shown excellent solubility and filterability in various brines. The dissolution characteristics are excellent and very similar to standard HPAM. Aspiro™ P 62XX polymers are designed for mild field conditions. These polymers yield high mobility reduction at a significantly lower dose level compared to standard HPAM. Aspiro™ P 66XX polymers have been developed for use in harsh conditions. Their distinct performance profile is based on a unique, thermally stable hydrophobic component. The hydrophobe-hydrophobe interaction becomes even stronger with increasing temperature. A major advantage of this thermo-associative effect is, that the initial viscosity is maintained or even increased over a wide temperature range. In contrast to this, standard polyacrylamides significantly lose viscosifying power with increasing temperature (see Fig. 9).

Fig. 8: Bulk viscosity of Aspiro™ P 6201 associative polymer compared to standard PAM with increasing temperature





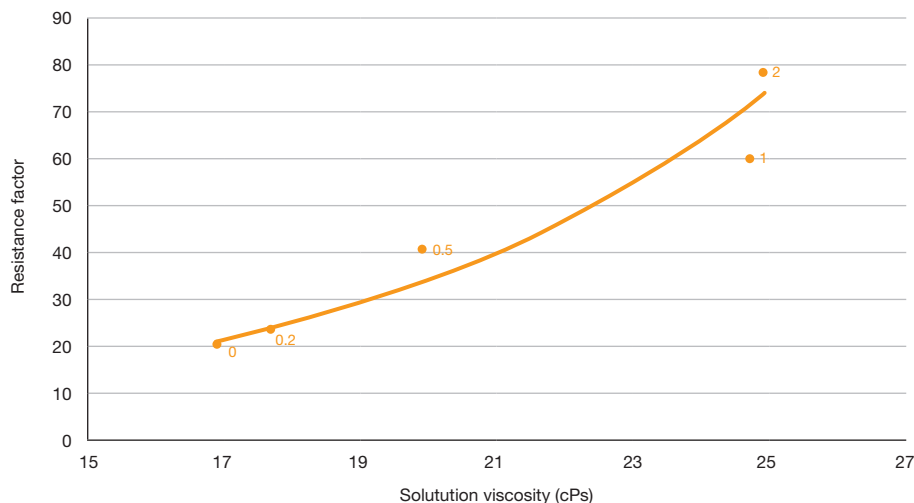
# Associative polymers – performance evaluation

## Unique rheology profile of associative polymers in porous media

The rheology behavior of associative polymers in porous media flow is significantly different from that of standard HPAM. While standard polyacrylamides exhibit a linear increase of the resistance factor with increasing bulk viscosity of the polymer/brine solution, associative polymers show an exponential increase of the in-situ viscosity (see Fig. 9). Thus, the performance of associative polymers can be hardly assessed from measuring bulk rheology. It is decisive for associative polymers to perform porous media flow experiments in order to assess their true performance. We recommend to perform coreflood experiments – preferably in the presence of oil.



Fig. 9: Coreflood experiments on polymers with rel. associative content ranging from 0 to 2



Anton Paar Physica MCR301, cone plate geometry;  
shear rate  $10 \text{ s}^{-1}$   
 $T = 20^\circ\text{C}$   
Brine: 10,000 ppm TDS, no divalents  
Polymer concentration: 1,000 ppm  
Serial dual-core set-up: length 7 cm each,  
Bentheimer sandstone  
Brine injection starting @ 1 ml/min with rate steps  
up to 50 ml/min

# How to evaluate associative polymers?

While the resistance factor and the network strength generated for associative polymers strongly depend on temperature and salinity conditions, further key performance parameters like injectivity, propagation profile, and retention are impacted also by these parameters. We adjust the chemistry of our **Aspiro™ Polymers** in order to cope with technical requirements over a broad range of field conditions.

Aspiro™ P 6201 is our associative polymer for low temperature, low salinity applications. As can be seen in Fig. 10–12 it shows good injectivity, excellent propagation, as well as low adsorption under the conditions stated. Aspiro™ P 6631 provides improved temperature stability as well as excellent salt tolerance – it is therefore designed for more challenging field conditions under which high to very high resistance factors can be achieved.

## Injectivity

— Aspiro™ P 6201

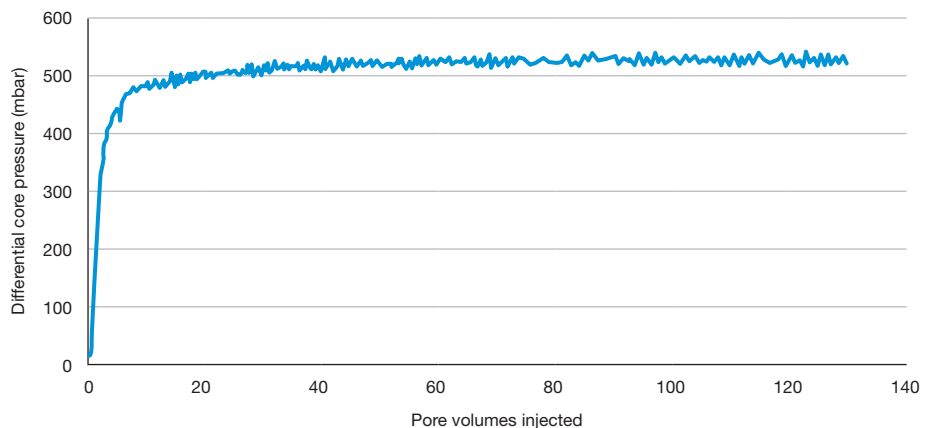
Good injectivity

$p_{max} = 1 - 5 \text{ PV}$

$p_{plateau} = 5 - 20 \text{ PV}$

Flooding experiment with serial dual-core set-up: length 7 cm each, Bentheimer sandstone; polymer concentration: 750 ppm, temperature: 50 °C; brine: 16,500 TDS with 1,000 ppm divalents; brine injection: 1 ml/min

Fig. 10: **Coreflood experiment of Aspiro™ P 6201 proves good injectivity by differential pressure reaching a steady state**

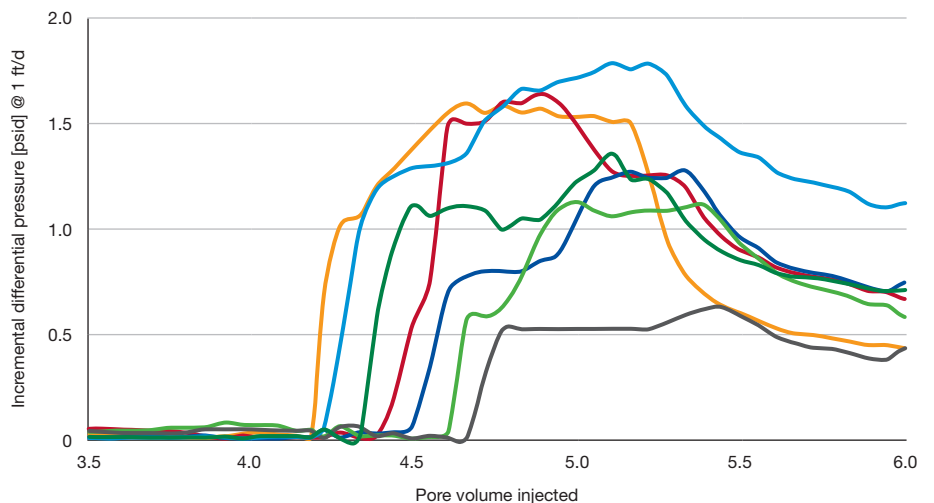


## Propagation

— dp1 — dp5  
 — dp2 — dp6  
 — dp3 — dp7  
 — dp4

Coreflood with oil, Core: Bentheimer Sandstone; brine: 20,000 TDS; temperature: 29 °C; waterflood until Sor; Polymer injection 1 ft/day (1 PV); Polymer concentration 1,000 ppm; post water flush 4 PV

Fig. 11: **Propagation of Aspiro™ P6201 polymer front slug monitored by increasing differential pressures along the full core length (12 inches)**



## Adsorption

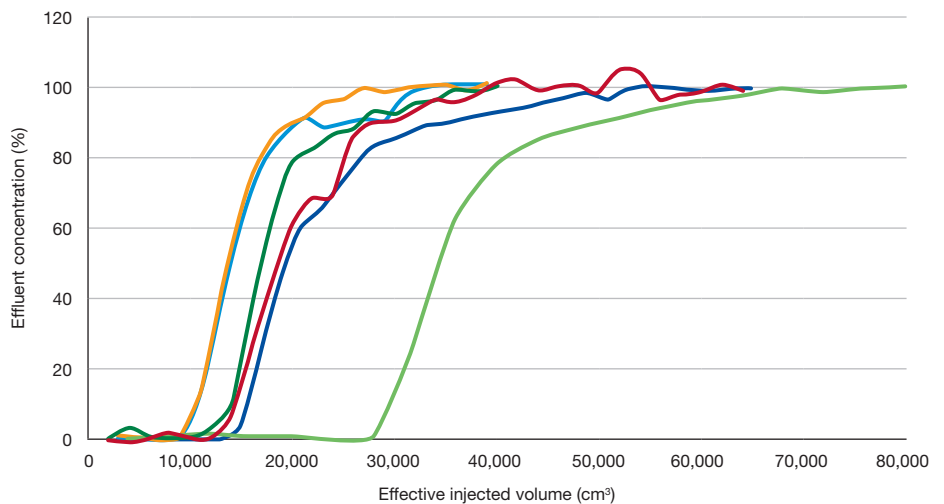
— TOC 1      — TOC 2  
— TON 1      — Tracer 2  
— Tracer 1  
— TON 2

Adsorption: 33 µg/g of rock

Inaccessible pore volume (IPV): 0.25

Polymer concentration 750 ppm; brine 16,000 ppm TDS; 1,000 ppm divalents; Bentheimer sandstone core (12 inches); flooding until Sor and injection of polymer, three pressure tabs along the core; determination of adsorption via effluent analysis regarding polymer concentration by total organic carbon (TOC) and total organic nitrogen (TN) relative to initiated polymer concentration

Fig. 12: Low adsorption for Aspiro™ P 6201



# Selecting the right product for your field

Due to excellent compatibility of our associative polymers with BASF Aspiro™ Surfactants, our products are in general a great choice for alkaline-surfactant-polymer or surfactant-polymer projects.

Each polymer flooding project is different and requires a variety of different disciplines to be involved. Especially the number of variables involved in the design of a polymer project can make the undertaking a quite complex scenario in which many parameters have to be considered, e.g. monomer selection, polymer structure, dissolution techniques, injection systems, injection water, product logistics, supply chain aspects and many more. BASF provides a wide range of expertise to make your operations more successful. Our dedicated teams are well prepared to support you to identify the best solutions that fit your company requirements and your reservoir conditions. We are experts in delivering large quantities of product around the world and ensure reliable supply with the scale to grow your business.



## **North America**

### **BASF Corporation**

Oilfield Solutions  
3120 Hayes Road  
Suite 200  
Houston, TX 77082  
US  
Phone: +1 800 7941019  
Fax: +1 877 2451806

## **Europe**

### **BASF SE**

Oilfield Solutions  
G-EVG/EO – D 105  
67056 Ludwigshafen  
Germany  
Phone: +49 621 60-0

## **Asia**

### **BASF South East Asia Pte. Ltd.**

Oilfield Solutions  
33 Tuas Avenue 11,  
Singapore 639090  
Singapore  
Phone: +65 6860 7053

## **South America**

### **BASF S.A.**

Oilfield Solutions  
Avenida das Nações Unidas,  
14.171 Morumbi  
04794-000 São Paulo  
Brazil  
Phone: +55 11 2039-3482  
Fax: +55 11 2039-2786

## **Middle East / North Africa**

### **BASF Middle East LLC**

Oilfield Solutions  
P. O. Box 2996  
Dubai  
United Arab Emirates  
Phone: +971 4 8072222  
Fax: +971 4 8072149

### **For further information:**

[oilfieldsolutions@basf.com](mailto:oilfieldsolutions@basf.com)  
[www.oilfiels-solutions.basf.com](http://www.oilfiels-solutions.basf.com)

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