SURFACE ISSUES

Water quality
Powder vs emulsion polymers
Fluid transfers & gas blanketing
Dissolution equipment
Distributing fluid to injectors
Issues in production wells
Oil/water separation

WATER QUALITY (mostly from SNF)

Salinity/Hardness: Economic issue. **As TDS increases from 500 to 5000-ppm, HPAM viscosity drops 3.5X.**

Particulates: < 20 ppm, size < 5 μm.

Oil content: **< 100 ppm (often economic to achieve less).**

Dissolved oxygen: < 20 ppb for T<50°C. Strive for 0 ppb at higher T. (Strive for 0 ppb at low T also.)

Fe^{2+}: **Some people list an Fe^{2+} limit, but I advocate leaving the iron in solution and minimizing oxygen.**

Microorganism content: Limit growth so it does not interfere with injectivity or operations.

Powder versus Emulsion Polymers
SPE 179631 (Total) and SPE 179657 (Chevron)

- Emulsion polymers require less CAPEX and footprint and dissolve faster.

BUT…

- They cost more.
- Have higher transportation costs.
- Can show plugging/injectivity impairment associated with the oil phase.

CONTROLLING DISSOLVED OXYGEN IS CRITICAL!

- Water floods are often performed with little regard to oxygen leaking into the flow stream.
- You MUST minimize dissolved oxygen in polymer flooding!
- Any O_2 leaking into the flow stream degrades the polymer and costs you LOTS of money and problems!
- Below 50°C, keep dissolved O_2 below 50 parts per billion (ppb).
- Above 50°C, it is critical to keep O_2 below 10 ppb!!!
- It is EASY and LOW-COST to minimize dissolved O_2. It just requires a different way of thinking than in a waterflood.

Fluid Transfers

Gas/oxygen entrainment can be minimized by piping fluid into tanks below the liquid surface.

Gas Blanketing

Gas blanketing tanks is reasonably economic for storage and transfer tanks. In contrast, blanketing the powder feed and storage hoppers can be expensive. Solution: introduce a nitrogen sparge line into the powder hopper cone just above the eductor or slicing unit.

MAKE SURE YOUR POLYMER IS DISSOLVED!!!

- If you have big viscosity variations, or find polymer gel in your wellbore, you are not dissolving your polymer well enough!

- Filter tests are time-consuming and worthless if you don't make sure your polymer is completely dissolved.

- Undissolved polymer is costly and can be damaging!

- YOUR ONSITE OPERATORS MUST UNDERSTAND THE ABOVE!

- Perhaps better onsite criteria for properly dissolved polymer are:
  1. Strive for consistent on-site viscosity values that are reasonably close to lab solutions.
  2. Continuously monitor pressure drop across a sock filter—because ALL fluid passes through it.
  3. Achieve smooth flow with no lumps as polymer solution is slowly poured in a thin film from one beaker to another.
  4. DO SOMETHING IF YOU SEE A PROBLEM!

Powder Polymer Dissolution Equipment

Eductors (high-energy water jets):

- Simple, low cost, easy to maintain.
- More difficult to exclude air/oxygen.

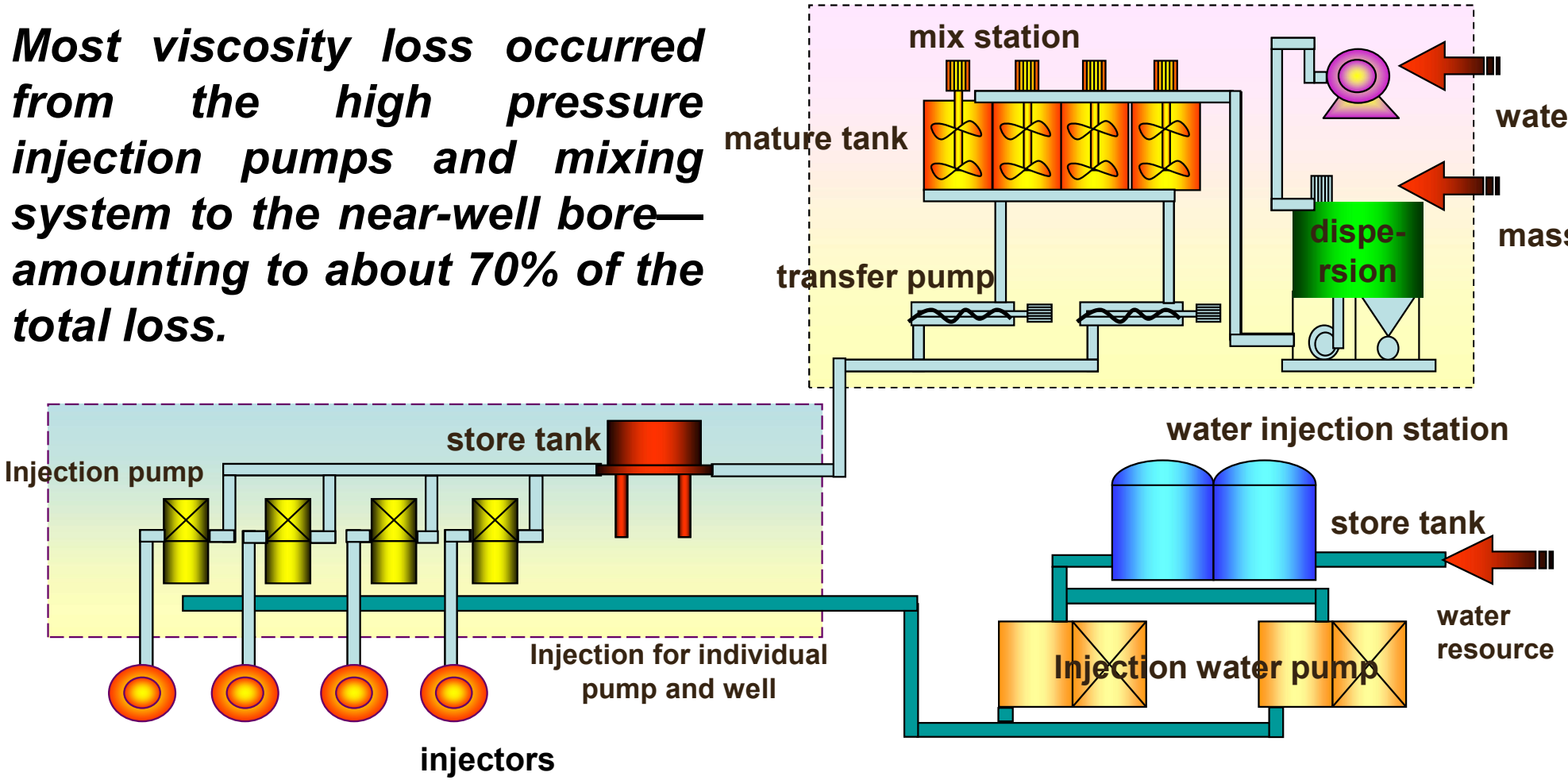
Polymer slicing units:

- 2X to 4X faster polymer dissolution.
- Can make more concentrated mother solutions.
- More compact. More workable in controlled gas environments (H_2S or O_2-free).
- More expensive, higher maintenance costs.

Recent papers on startup & facility issues (pumps, tank mixers, filters, monitoring, logistics):
SPE 77496, 114342 (Daqing), 135735 (Total),165308 (Chang), 174350 (OMV), 174537 (IFP), 179807, 179820 (Cairn), 155116 (Shell).

Daqing Mixing and Injection (from D. Wang, *SPEREE* 2009, SPE 114342)

Most viscosity loss occurred from the high pressure injection pumps and mixing system to the near-well bore—amounting to about 70% of the total loss.



Flow illustration for polymer injection

First Polymer Injection in Deep Offshore Field Angola: Recent Advances on Dalia/Camelia Field Case

Danielle Morel and Michel Vert, Total E&P; Stéphane Jouenne, Total Petrochemicals France; and Renaud Gauchet and Yann Bouger, Total E&P Angola

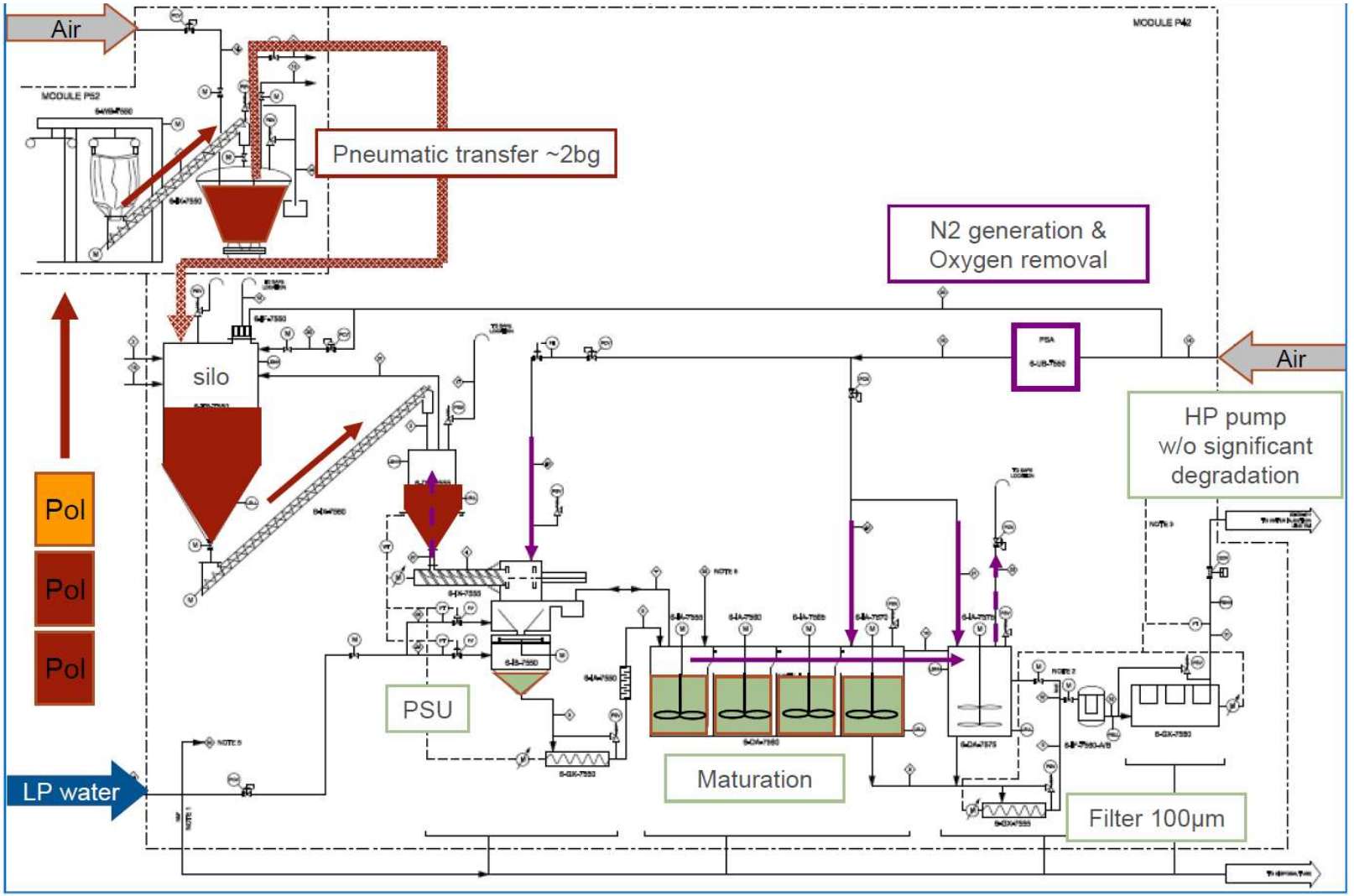


Figure 6 - Schematic of the powder polymer process

HPAM Mechanical Degradation in Pipes

SPE 169699: Jouenne et al. (Total)

HPAM mechanical degradation is low for velocities up to 3.7 m/s for pipes larger than 6-inch ID, for any length.

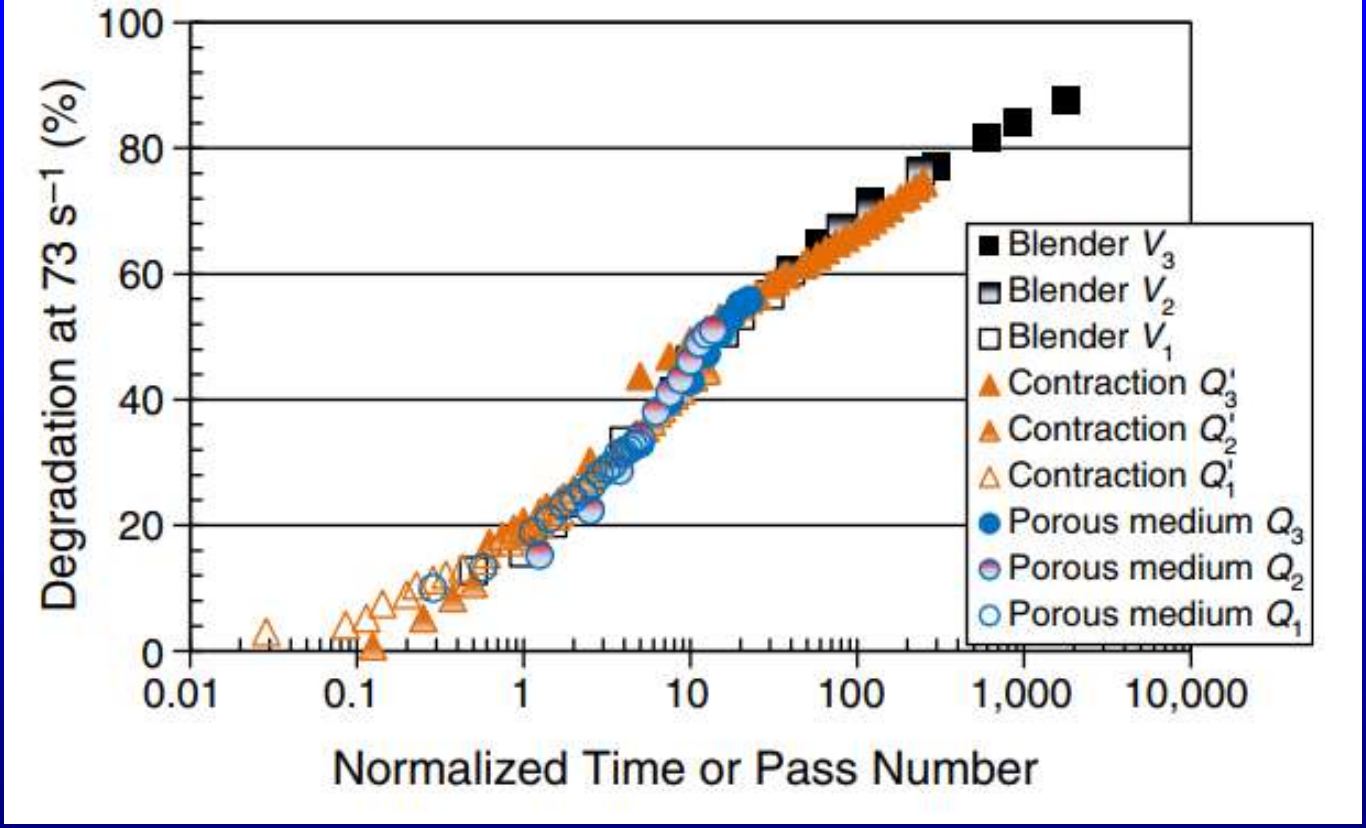
- **3630S HPAM concentrations from 300-2000 ppm.**
- **Distances up to 7500 meters.**
- **50°C and 0.6%-TDS brine.**

With 1200 ppm HPAM, mechanical degradation is:

- **~0 for up to 4 m/s in 0.98-inch-ID pipes.**
- **<10% for up to 7 m/s in 0.74-inch ID pipes.**
- **~0 below 2 m/s in 0.49-inch ID pipes.**

HPAM Mechanical Degradation after Sequential Exposures SPE 186103: Jouenne et al. (Total)

- Reviewed literature on mechanical degradation.
- Propose an empirical correlation between % loss of viscosity and (1) time in a blender, (2) flow through a contraction, and (3) flow in porous media.
- The correlation has potential but needs further testing.



SPECIAL ISSUES ASSOCIATED WITH USING VISCOELASTIC HPAM SOLUTIONS
Wang Demin et al. *SPEPF* (2004) SPE 77496

Problem: Inefficient polymer mixing in tanks.

Solution: Re-designed mixing blades reduced energy requirements 80% and reduced mixing time by 1.5-2 hours.

Problem: 10-30% shear degradation in static mixers.

Solution: Remove the static mixer.

SPECIAL ISSUES ASSOCIATED WITH USING VISCOELASTIC HPAM SOLUTIONS

Wang Demin et al. *SPEPF* (2004) SPE 77496

Problem: Pumping 0.5% HPAM solutions substantially increases vibration, especially upstream of pumps.

Solution: Use large diameter pipes, avoid T's.

SPECIAL ISSUES ASSOCIATED WITH USING VISCOELASTIC HPAM SOLUTIONS

Wang Demin et al. *SPEPF* (2004) SPE 77496

Problems with triplex pumps with HPAM:

- **High vibration.**
- **10-15% lower pump efficiency.**
- **15% viscosity loss from shear degradation.**

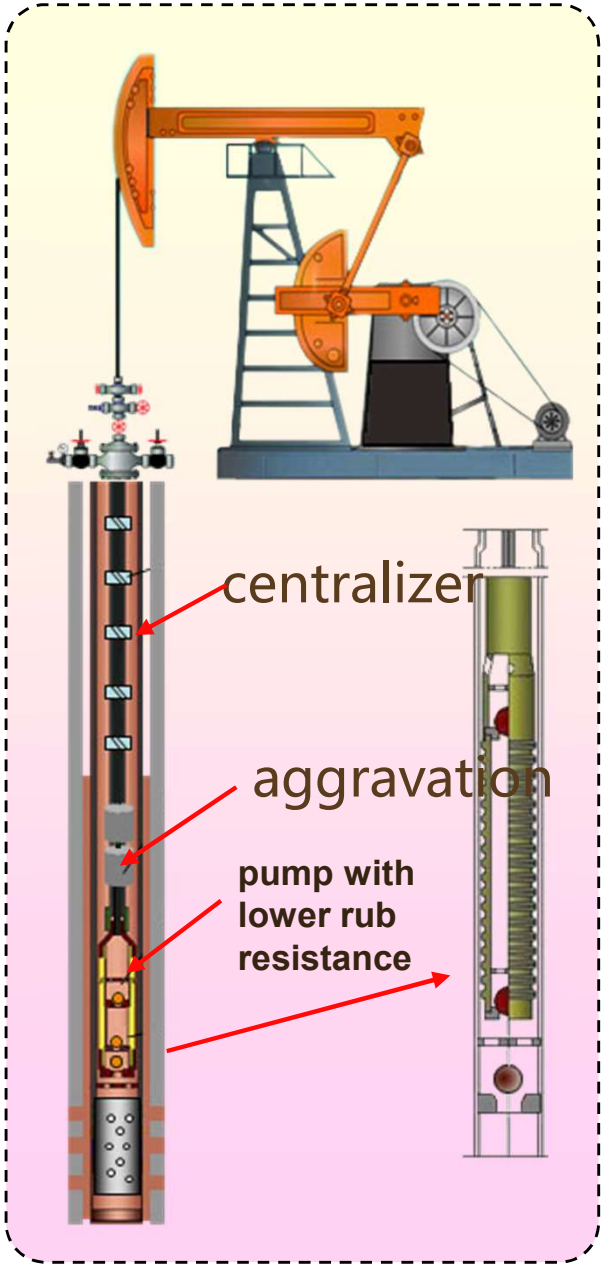
Solution: Re-design the pumps.

- **Decrease valve seat area.**
- **Adjust the angle of the valve seat.**
- **Increase inner cylinder diameter**
- **Decrease dead-end volume.**

Wang Demin et al. *SPEPF* (2004) SPE 77496

Techniques were developed using modified sucker rods to reduce pump resistance and frictional wear. The period of pump examination can be increased to 696 days from 277 days.

Produced HPAM solutions (500 ppm) reduced the service life of centrifugal pumps by 50%.



Control of fluid distribution to injection wells

One pump per injection well.

Flow restriction devices:

- In-line sand packs (SPE 8202, W Yellow Creek)
- Coiled tubing (SNF and CAPSA, SPE 166255)
- Low-shear valve (Chang, SPE 165308).

YPFs' Distributed Polymer Injection Concept (SPE 209364)

1. Identify "sweet spots" within the field.
2. Prioritize the best candidates.
3. Optimize to identify how many locations should be polymer flooded now under the current conditions.
4. Use skid/container mounted polymer injection units (instead of a central facility).
5. Move to the next location when appropriate.

YPFs' Distributed Polymer Injection Concept (SPE 209364)

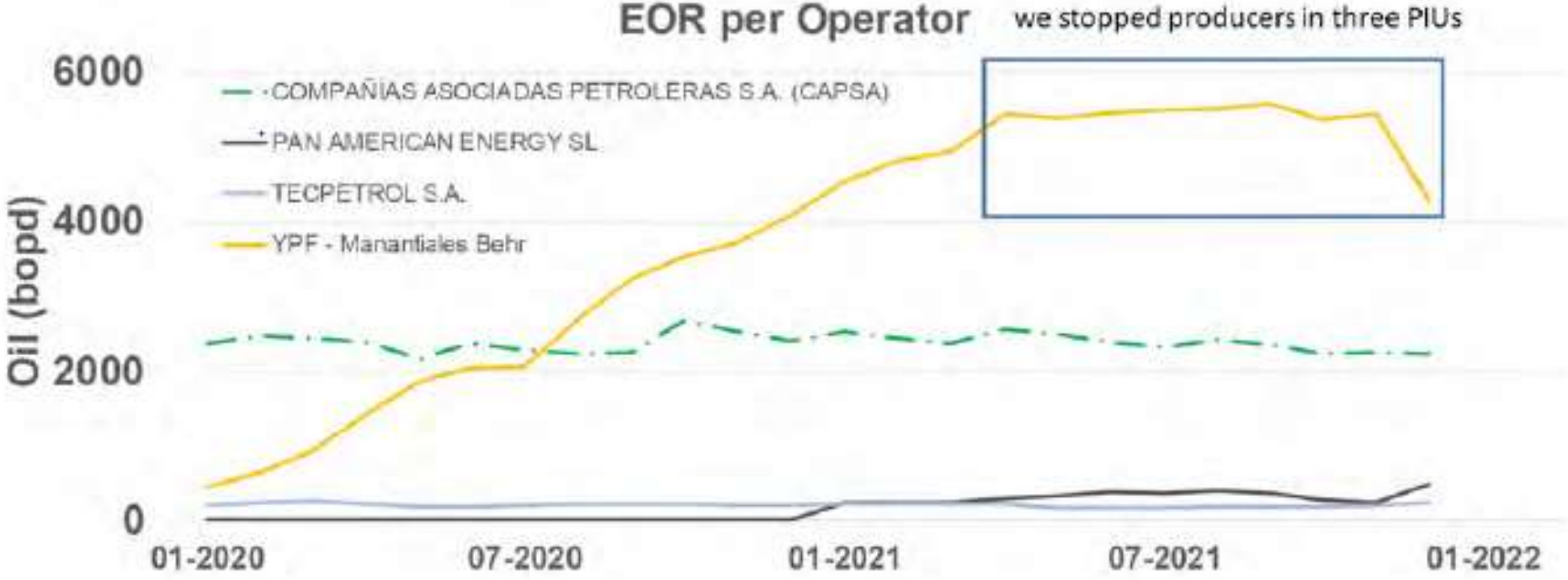


Figure 10—EOR production per Operator in Argentina (Source: Argentina Energy Secretary. Ministry of Economics https://www.argentina.gob.ar/economia/energia/hidrocarburos/visualizaciones-tableros).

PROBLEMS WITH PRODUCED POLYMER

- Excessive wear for sucker rods (SPE 77496).
- Emulsions that are difficult to break.
  - Fouling of heat exchangers & fire tubes (SPE 14110, SPE 144322).
  - Efficiency reductions for hydrocyclones and gas floatation units (SPE 95343).
- Plugging filters (SPE 144277).
- Inability to reuse produced water for polymer flooding.

POTENTIAL SOLUTION: Improve sweep to delay polymer breakthrough:

- Increase polymer concentration & viscosity.
- Gel treatments to reduce severe channeling.
- Separate layer injection.

IDEAS TO TREAT PRODUCED POLYMER

- Extended gravity separation (SPE 114342).
- Hydrocylone (SPE 95343).
- Modified heater treaters (170172).
- Oxidation (SPE 174683).
- Shearing through choke valves or centrifugal pumps.
- Flocculation with bentonite & pH changes (SPE 179525).
- Treatment with polyaluminum chloride or aluminum sulfate (SPE 172024) or iron chloride (SPE 174683).
- Addition of cationic polymers/surfactants (SPE 140860, SPE 169718, 177501).
- Removal using magnetic nanoparticles (SPE 179576).

KEEP HEATER-TREATER SKIN TEMPERATURES BELOW 250°F

- HPAM hydrolyzes at high temperatures, and precipitates with divalent cations.
- This fact causes heater-treaters to foul when polymer is produced if the skin temperature is too high.
- With normal throughput rates in heater-treaters at Milne Point, this problem can be avoided by keeping the skin temperature below 250°F.
- Incidentally, Chevron recently reported that a skin temperature up to 325°F can be used if the polymer contains 25% AMPS.

IMPACT OF LIFT METHOD IN PRODUCTION WELLS

- If you want to recycle your produced polymer, don't use an ESP or jet pump.
- ESPs severely degrade the polymer (by ~70%).
- Jet pumps substantially dilute the polymer.
- ESPs and jet pumps get hot—hydrolyzing HPAM to high levels, creating a gel mess with divalent cations. (SPE 206146).
- Progressive cavity pumps and rod pumps are much cooler and don't degrade HPAM (SPE 164121).
- Surface-flowing production wells also minimize HPAM degradation (SPE 208611).

POLYMER FLOODING is best for improving sweep in reservoirs where fractures do not cause severe channeling.

- **Great for improving the mobility ratio.**
- **Great for overcoming vertical stratification.**
- **Fractures can cause channeling of polymer solutions and waste of expensive chemical.**

GEL TREATMENTS are best treating fractures and fracture-like features that cause channeling.

- **Generally, low volume, low cost.**
- **Once gelation occurs, gels do not flow through rock.**