# Application of the Radioactive Tracer Log for Flow Measurement in Polymer Injection Wells*

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## Abstract

Enhanced Oil Recovery (EOR) technologies assessment aims to increase the recovery factor from mature fields. To achieve this objective the work is directed to progressively reduce uncertainty by recording and evaluating laboratory and field information, as well as performing forecasts using modeling and simulation. In this context of technological exploration, implementation of a polymer injection pilot project challenges techniques and tools routinely used in secondary recovery.

One of these challenges is the measurement of polymer flow rate taken at each perforation. This parameter aids to optimize the efficiency of the CEOR process by allowing the evaluation of the sweep efficiency per layer and its evolution over time.

As part of a pilot project in the San Jorge Gulf Basin (Argentina) a polymer injectivity test was conducted in Well A. During this test the radioactive flow-log tool was used in an attempt to determine the fluid intake by perforations. This tool is commonly used for monitoring water injection in secondary recovery projects.

In water injection wells the flow is turbulent, which promotes the diffusion of radioactive tracers into the main stream of the well. But when the tool is used with polymer, due to the increased viscosity of the fluid, the flow regime becomes laminar, which impairs the tracer diffusion process. Thus, for polymer injectors, the flow-log tool response complicates the determination of flow rate received by each perforation. In order to better understand the process of measuring and estimating flow rates for each perforated interval in the well, the workflow applied consisted of the following steps:

- All records of operations carried out using the flow-log tool in Well A is thoroughly analyzed.
- Literature on the theory and practice of the flow-log tool and tracers was reviewed.
- Using the method proposed by the service provider and an alternative method, all records were reinterpreted, including both water and polymer injection for Well A.
- Computational fluid dynamic simulations (CFD) were conducted to better understand the phenomenon and evaluate the validity of the proposed alternative method of interpretation.

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# Application of the Radioactive Tracer Log for Flow Meassurement in Polymer Injection Wells

Silvio Figliuolo - Fernando Peñalba - Horacio Burbridge - Mat Ichard - Marcela Ravicule - Juan Juri - Ana María Ruíz

# Introduction

## Background

- ✓ Flow rate measurements by reservoir may contribute to determine polymer flooding project efficiency. Gerencia de Proyectos Especiales y Manantiales Behr staff (YPF S.A.).
- ✓ Information provided by the flow-log tool in use for flow rate measurements, during polymer injection, is confusing and difficult to interpret. The method used is not designed for the laminar flow conditions.
- ✓ Opportunity for identification/development of alternatives for EOR projects.

## Objective

- ✓ To provide reliable measurements of polymer flow rate distribution, by reservoir. This information should allow to evaluate polymer flooding efficiency.

# Workflow

Injection Well Characteristics

Tool Specifications and Operation Procedure

Measurement Process Review

Analysis of Results

Possible Solutions Breakdown

**Alternatives**

New Interpretation Method.

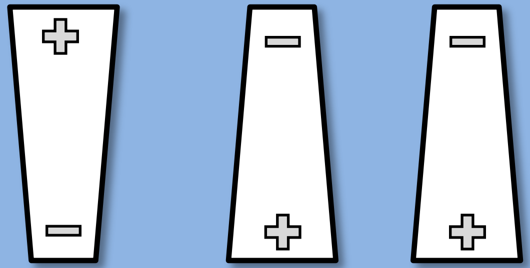
Logging Process Modification.

Tool reengineering and modification.

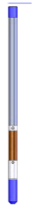
Alternative tools availbility.

New tool design project.

**Feasibility** | **Time for Implementation** | **Cost $**

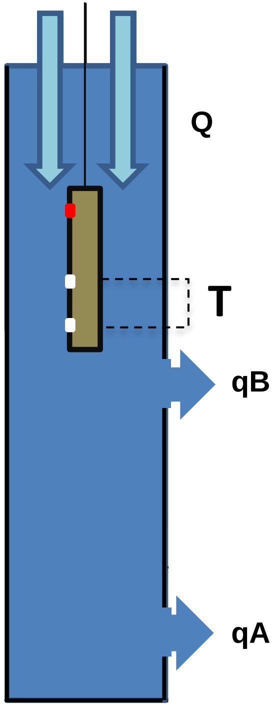


# Flow-Log Tool


| 1-3/8" CASING COLLAR LOCATOR | | |
|---|---|---|
|  | Diameter: | 1-3/8" (34.9 mm.) |
| | Length: | 21.5" (546 mm.) |
| | Pressure Rating: | 20.000 psi (137.9 MPa) |
| | Temperature Rating: | 350 ℉ (176 ℃) |
| | Operating Voltage: | 100 Vdc @ 15 mA |
| **1-3/8" TRACER EJECTOR** | | |
|  | Diameter: | 1-3/8" (34.9 mm.) |
| | Length: | 36.66" (931 mm.) |
| | Capacity: | 50 cc |
| | Pressure Rating: | 17.000 psi (117.2 MPa) |
| | Temperature Rating: | 350 ℉ (176 ℃) |
| | Operating Voltage: | 100 Vdc Positive → Fill<br>100 Vdc Negative → Eject |
| **1-3/8" GAMMA RAY DETECTOR** | | |
|  | Diameter: | 1-3/8" (34.9 mm.) |
| | Length: | 50.8" (1291 mm.) |
| | Pressure Rating: | 20.000 psi (137.9 MPa) |
| | Temperature Rating: | 350 ℉ (176 ℃) |
| | Operating Voltage: | 100 Vdc @ 45 mA |

# Logging Process Description

Rate = Volume / Time = Area * Length / Time = Area * Speed

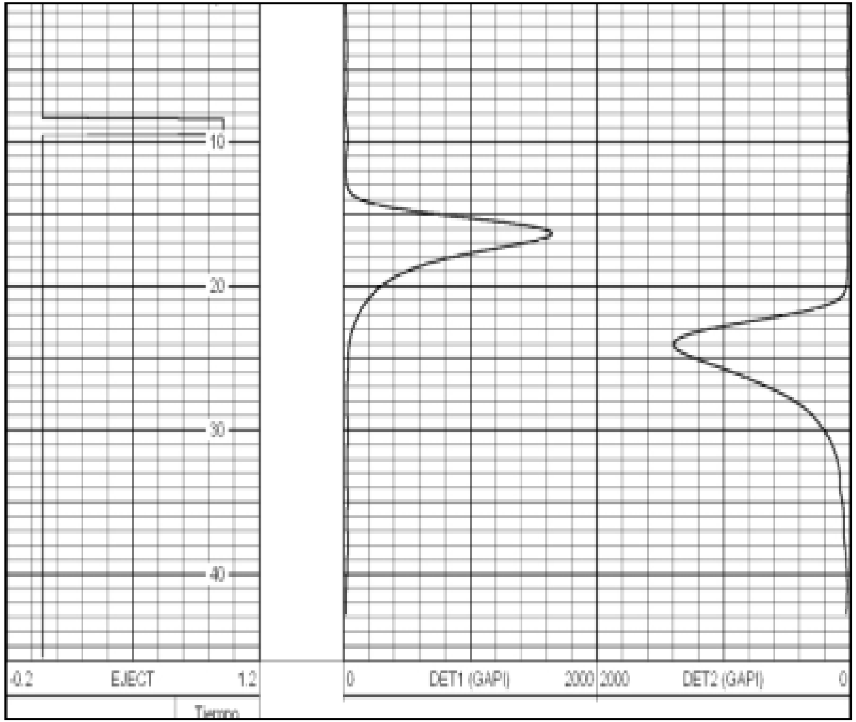


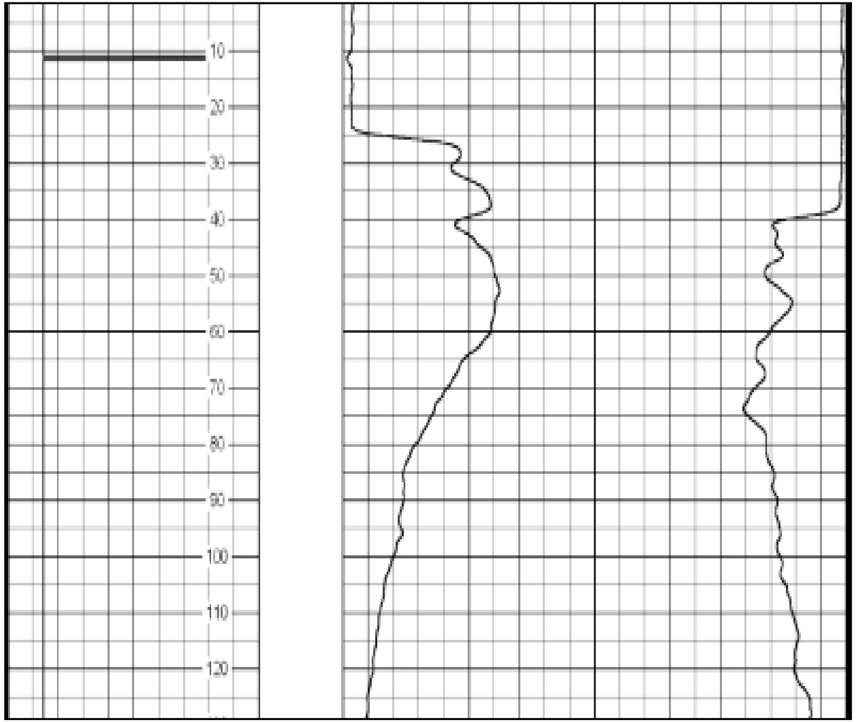

**T**: Total flow rate **Q**.

**t**: **qA** flow rate time

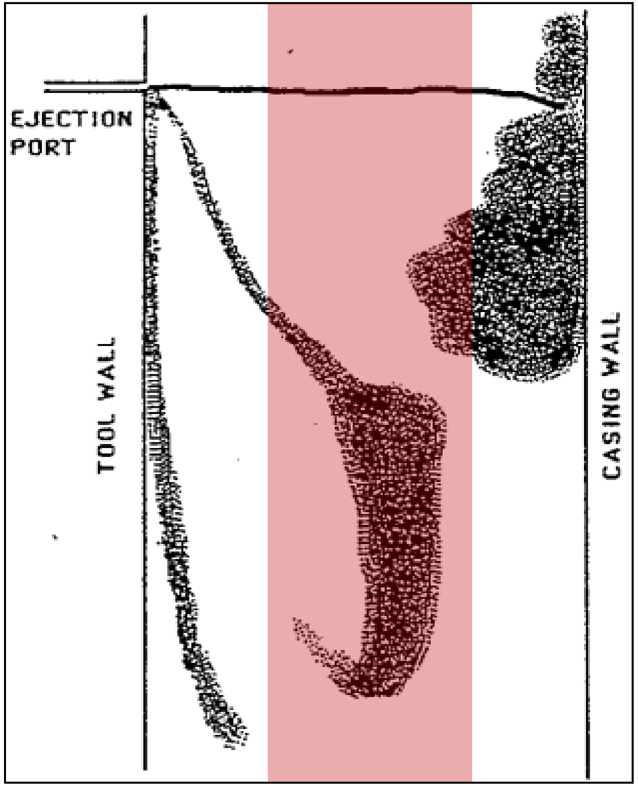
**qB= Q - qA**

# Field Data: Water and Polymer



# Laminar Flow Tracer Distribution - Literature

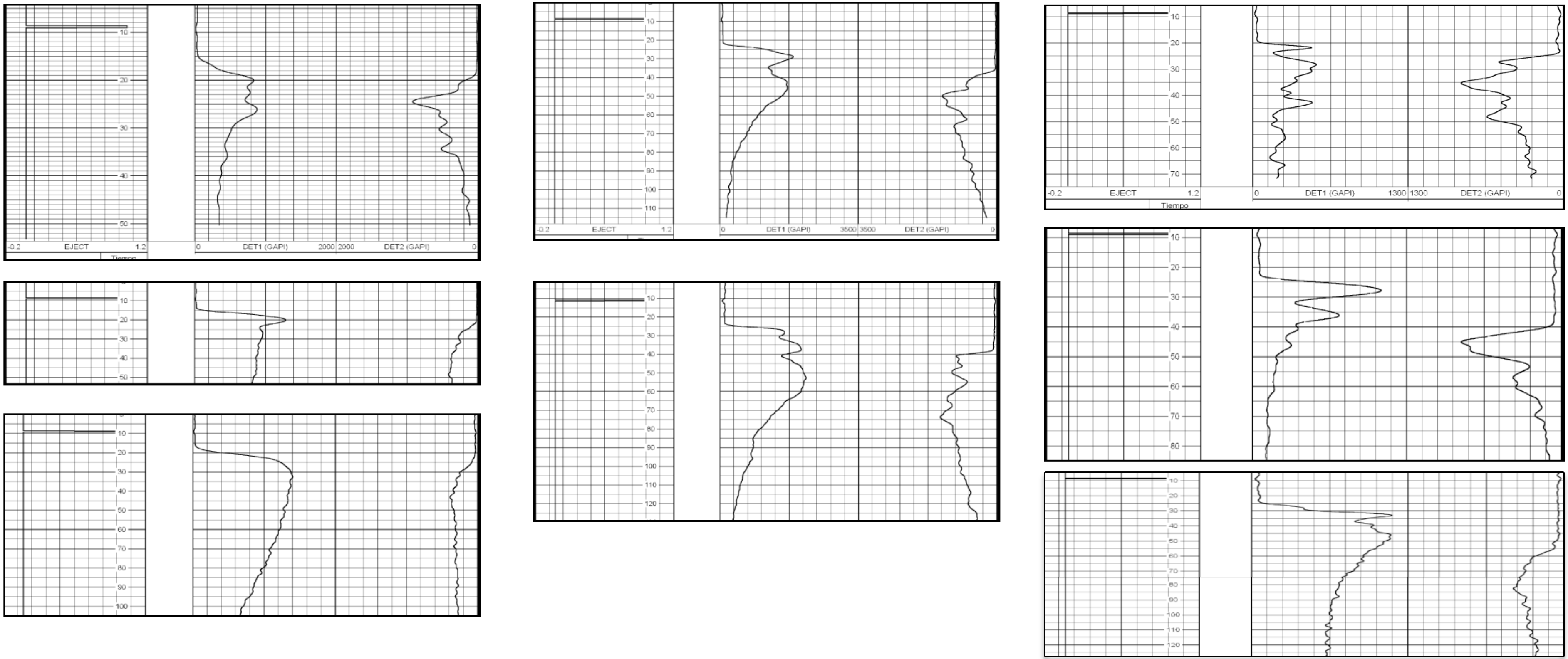



as it passed from the first detector to the second. When wellbore flow was laminar, the tracer dispersion could be predicted with a theoretical model and the experimental results compared well with the theory. As would be expected, optimal results were obtained when the bulk of the tracer was placed in the high-velocity, central

- “Tracer-Placement Techniques for Improved Radioactive-Tracer Logging”, Hil, Boehm, Akers, SPE17317, 1988

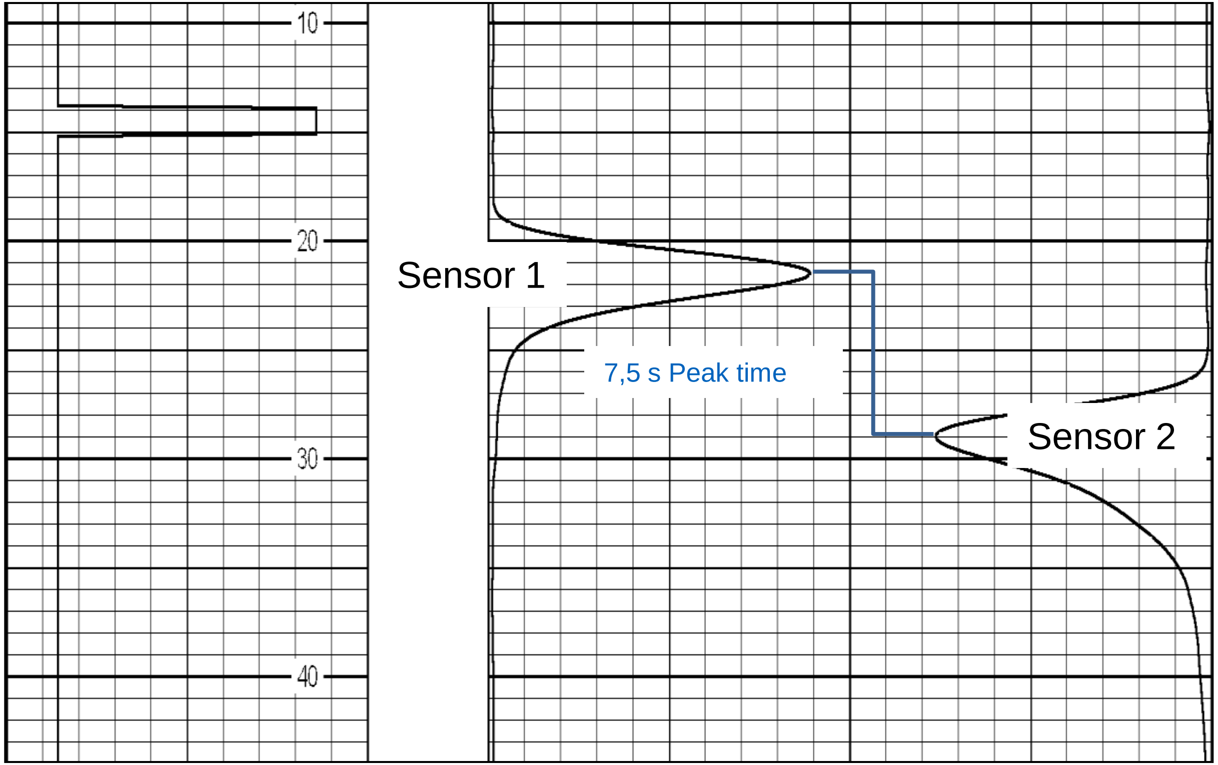
# Field Data Review

## Tracer concentration logs in polymer solutions



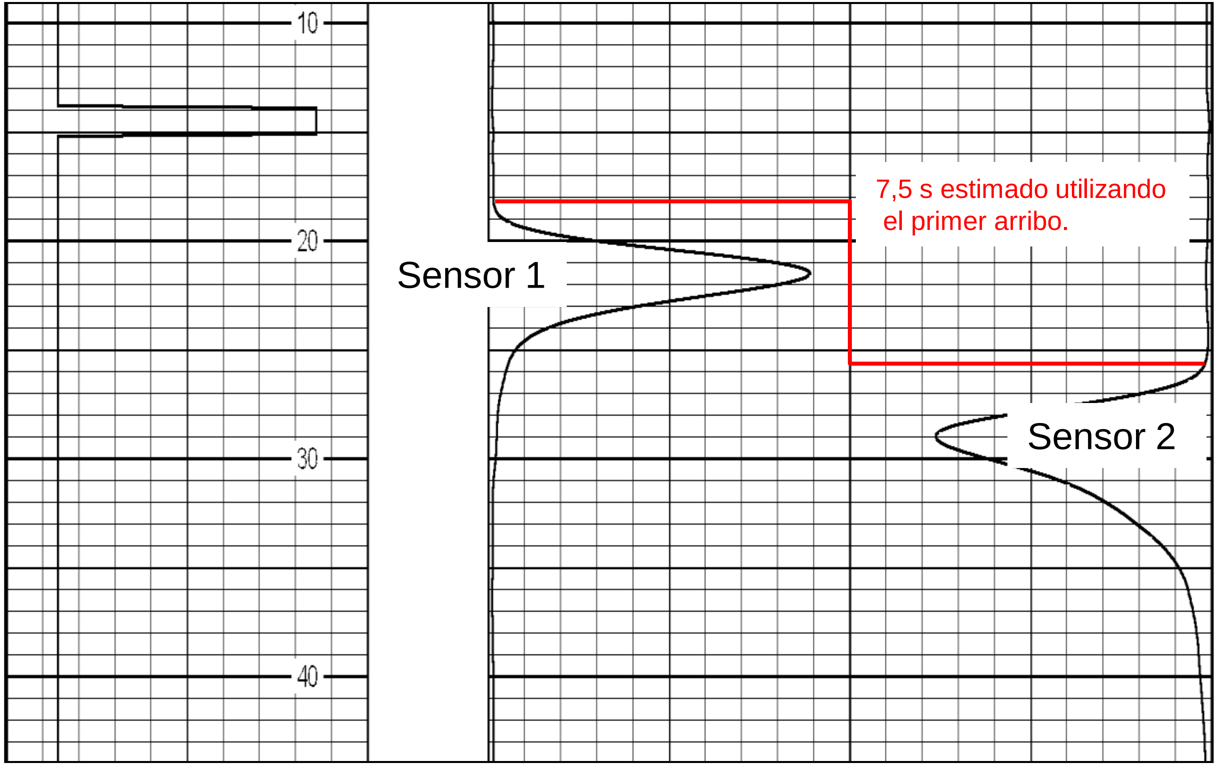
# Transit Time Estimation

**Concentration peak method**



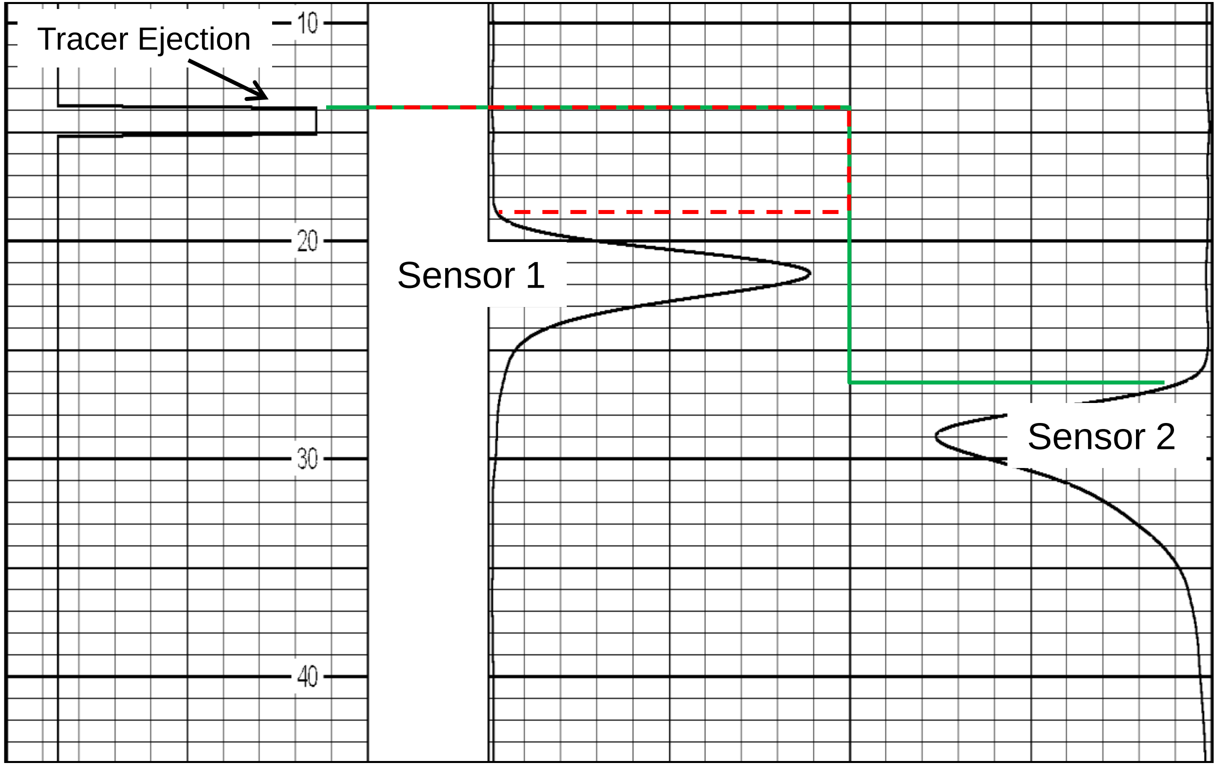
# Transit Time Estimation

**Tracer breakthrough method**

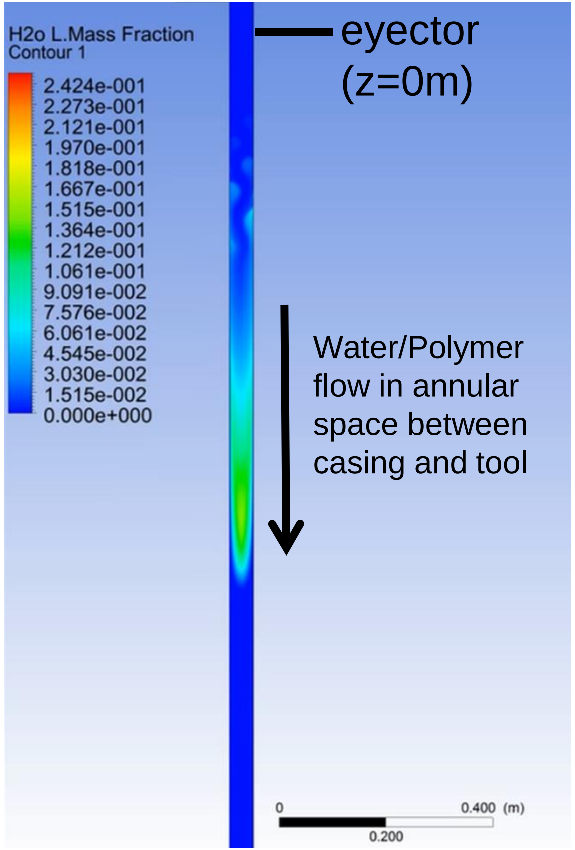


# Transit Time Estimation

**Additional Information (not used!)**



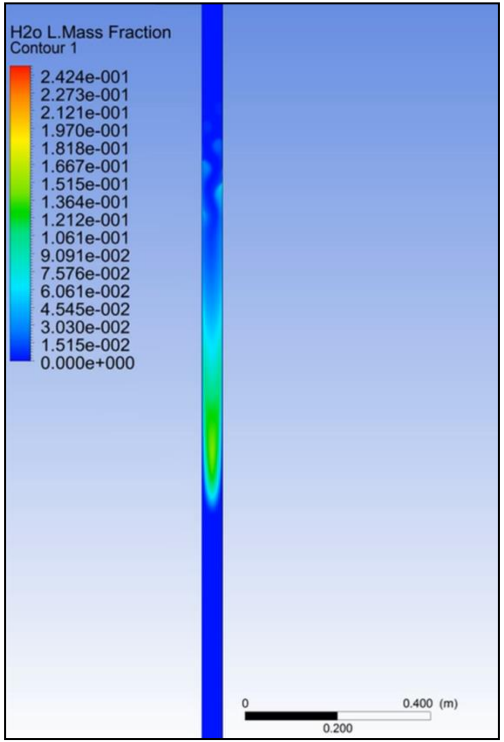
# CFD Simulation Set Up- 2D Model Preconditions

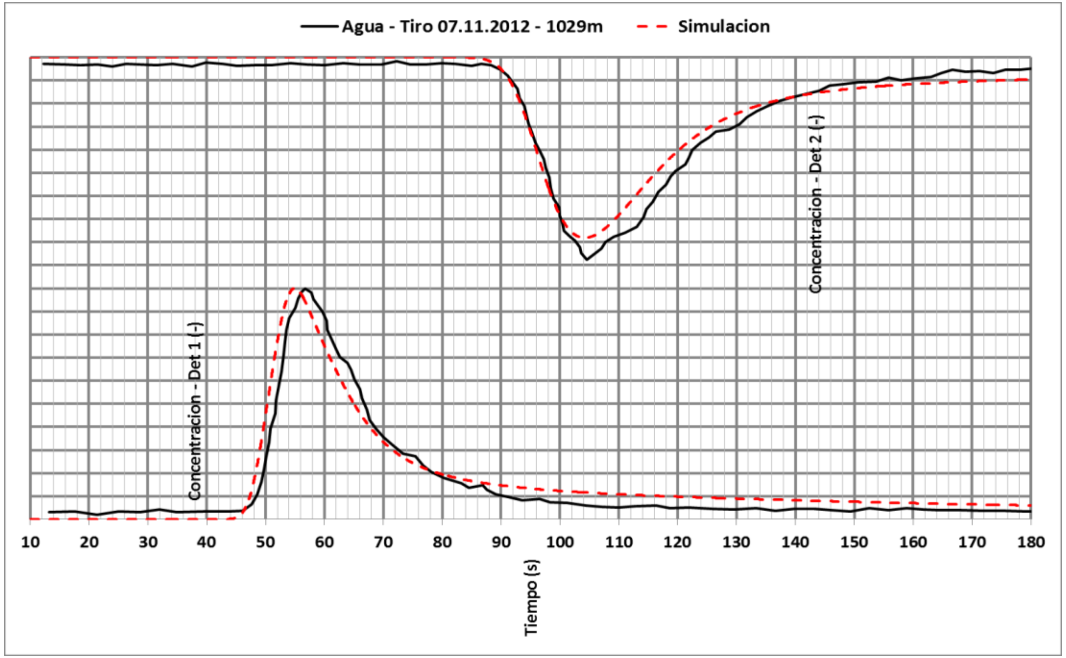



| | |
|---|---|
| Eyector diameter | 0.5 mm |
| Tracer ejection speed | 3.18 m/s |
| Tracer ejection length | 0.8 s |

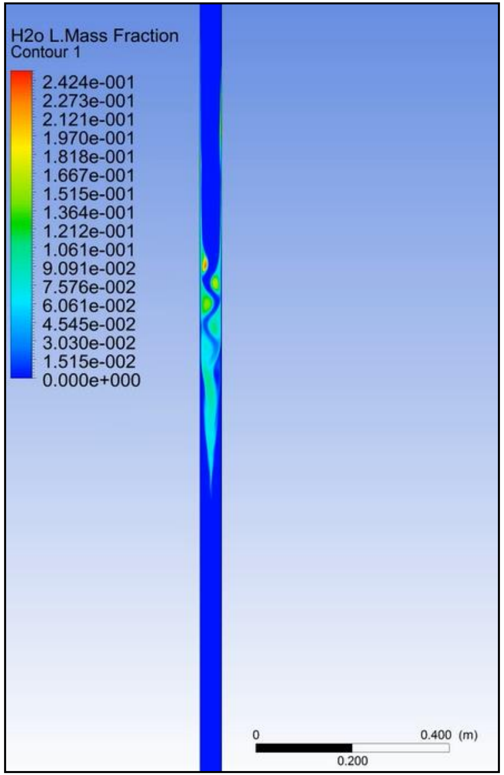
- Tracer concentration measured downstream in:
  - ✓ Detector 1 (z=-2.53 m)
  - ✓ Detector 2 (z=-5.64 m)
- Distance between detectors: Δ=3.11 m

# CFD Simulation Set Up – Tracer Difussion and Detection, Water

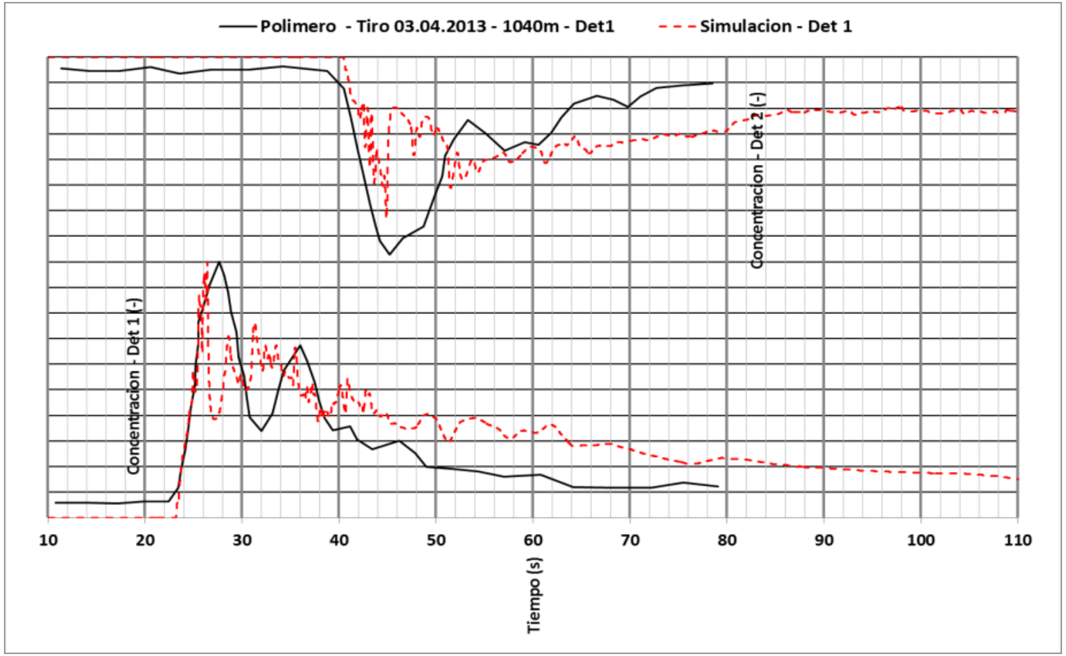


# CFD Simulation Set Up – Tracer Difussion and Detection Polymer

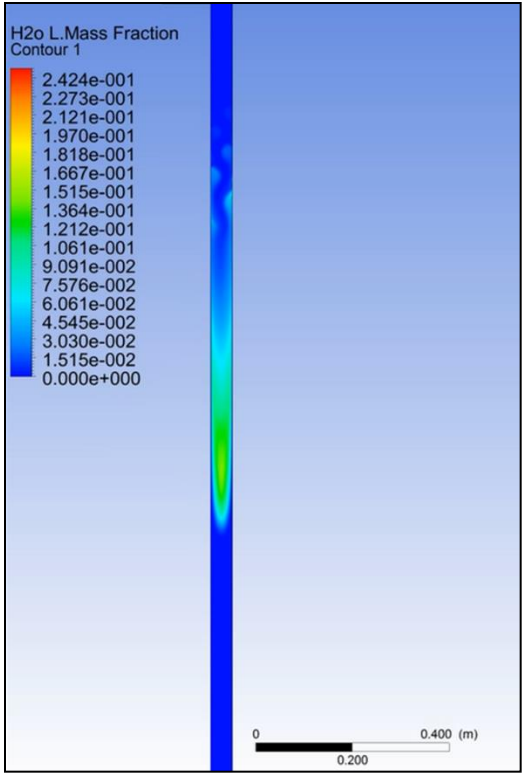



- ✓ Polymer viscosity is modelled using Carreau law for specific polymer and concentration, optimized for the reservoir.

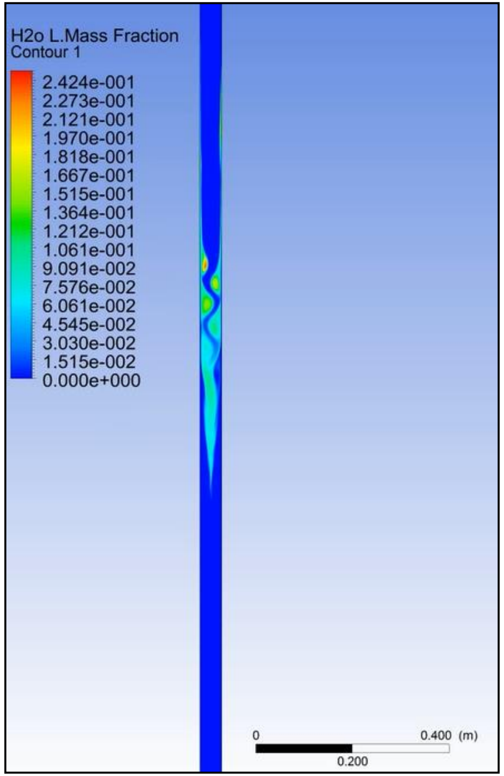


# CFD Simulation Set Up - Results

- CFD simulation succesfully reproduced radioactive tracer disperssion:
  - ✓ Turbulent flow in Newtonian fluids (water injection).
  - ✓ Laminar flow in Non-Newtonian fluids (polymer injection)



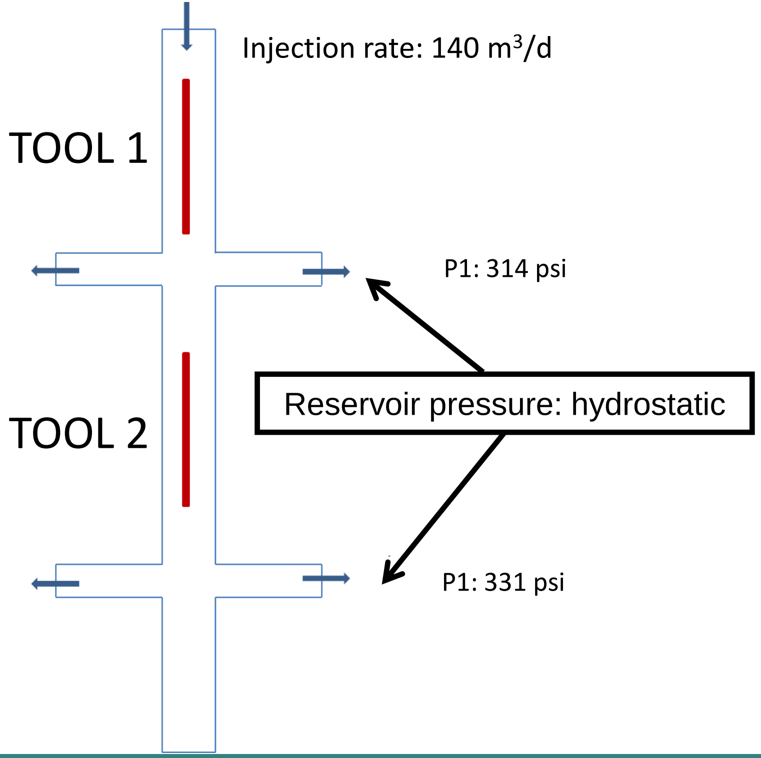

Water Injection



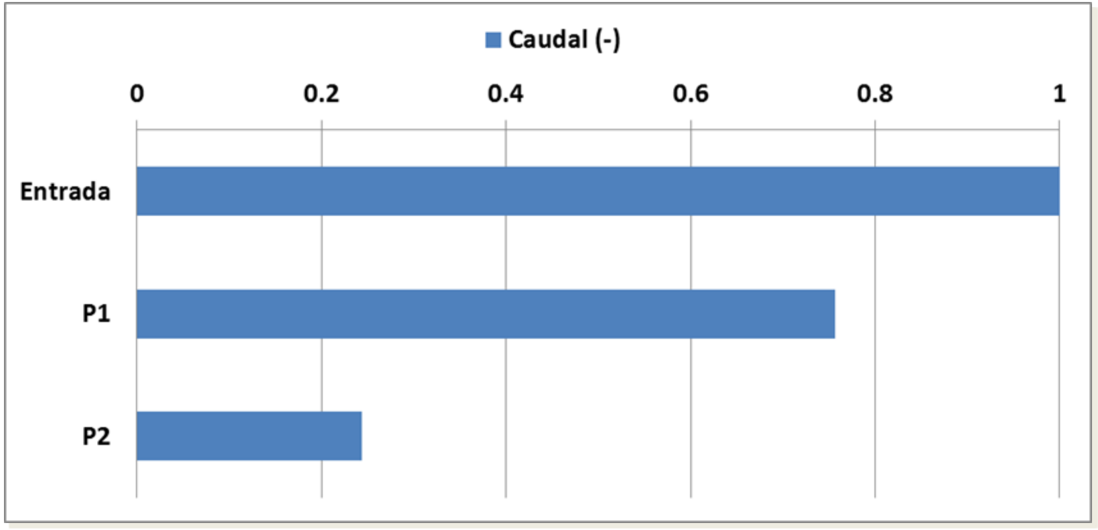

Polymer Injection

# CFD Simulation Tracer Breakthrough Flow Rate Estimation

1. CFD injection well model.

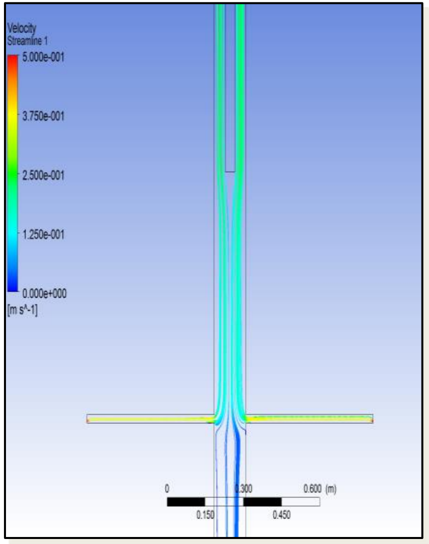



Flow rate distribution for each reservoir



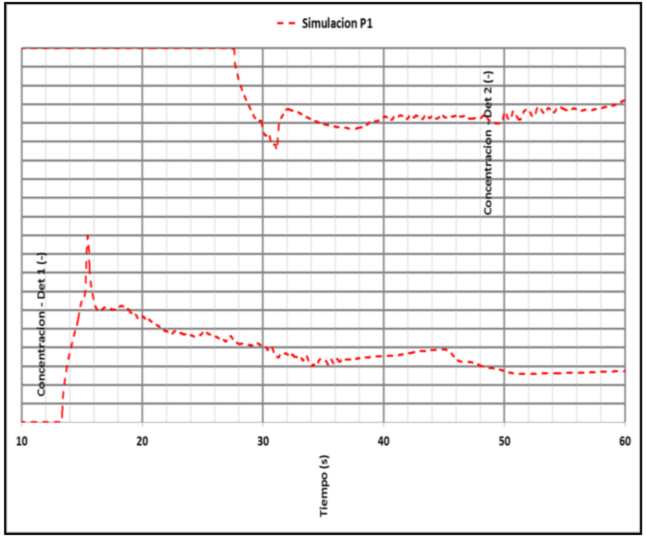
# CFD Simulation Tracer Breakthrough Flow Rate Estimation

2. Tracer difussion simulation and flow rate estimation (Tools 1 and 2).



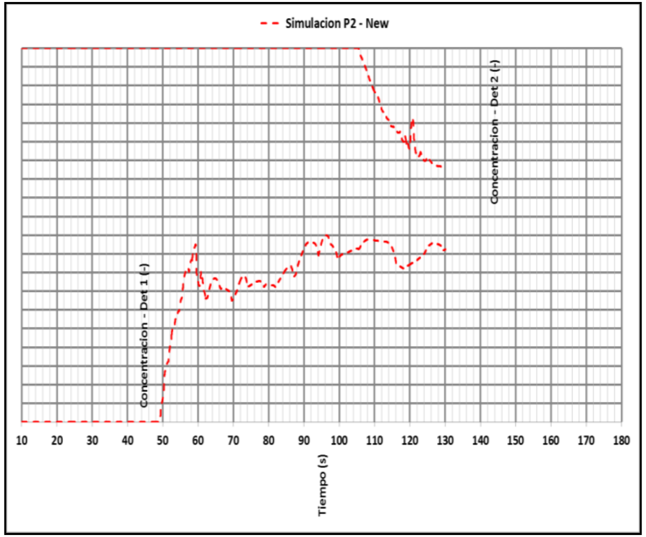

Streamlines en P1

TOOL 1




$t_{h1\_det1}$ = 13.4s ; $t_{h1\_det2}$= 27.4s ; $\Delta_{h1}$ =14.0s

TOOL 2




$t_{h2\_det1}$ = 50s ; $t_{h2\_det2}$= 106s ; $\Delta_{h2}$ = 56s

# CFD Simulation Tracer Breakthrough Flow Rate Estimation

3. Calculo de los caudales con el método de los primeros arribos.

| Reservoir | Simulated Rate ($m^3$/day) | Tracer Breakthrough Flow Rate ($m^3$/day) | Error |
|---|---|---|---|
| P1 | 105.9 | 105.3 | <1% |
| P2 | 34.1 | 34.7 | 2% |

# Tracer Breakthrough Injection Rate Estimation

## Flow Rates Estimation, Mean and Std Dev

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 03-abr | Csg | 5 1/2 | | 09-may | Csg | 5 1/2 | |
| 1027 mts | Q (Eyector - Detector 1) | 197,9 | | 1027 mts | Q (Eyector - Detector 1) | 197,9 | |
| | | | Prom y Desv std | | | | Prom y Desv std |
| | Q (Eyector - Detector 2) | 180,8 | 185,8 | | Q (Eyector - Detector 2) | 212,1 | 209,0 |
| | | | 10,5 | | | | 10,0 |
| | **Q (Det1-Det2)** | **178,8** | | | **Q (Det1-Det2)** | **217,2** | |
| 1040 mts | Q (Eyector - Detector 1) | 183,2 | | 1041 mts | Q (Eyector - Detector 1) | 206,1 | |
| | | | Prom y Desv std | | | | |
| | Q (Eyector - Detector 2) | 180,8 | 180,9 | | Q (Eyector - Detector 2) | 212,1 | Prom y Desv std |
| | | | 2,2 | | | | 211,8 |
| | **Q (Det1-Det2)** | **178,8** | | | **Q (Det1-Det2)** | **217,2** | 5,5 |
| 1054 mts | Q (Eyector - Detector 1) | 164,9 | | 1053 mts | Q (Eyector - Detector 1) | 164,9 | |
| | | | Prom y Desv std | | | | Prom y Desv std |
| | Q (Eyector - Detector 2) | 153,2 | 154,3 | | Q (Eyector - Detector 2) | 180,8 | 180,6 |
| | | | 10,1 | | | | 15,6 |
| | **Q (Det1-Det2)** | **144,8** | | | **Q (Det1-Det2)** | **196,2** | |

# Results

- ✓ Review and analyzed Flow-Log rate measurement and estimation process.
- ✓ Tracer Breakthrough provides reliable information on water injection rate.
- ✓ Agreement between field data (water and polymer) and tracer breakthrough using CFD simulations.
- ✓ Using CFD simulation the accuracy of polymer injection rates by reservoir, estimated using tracer breakthrough is 2%.
- ✓ Multiple sources of information (ejector-detector transit time) may contribute to measurements reliability.

# Next Steps

- ✓ Laboratory tests.
- ✓ Field test protocol.
- ✓ Technical support to provider.
- ✓ Field Test (design, implementation and evaluation) with field staff and provider.
- ✓ Documentation y final recomendations.