30TH ANNIVERSARY ADIPEC 2014

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CHALLENGES AND OPPORTUNITIES FOR THE NEXT 30 YEARS

19 October 2014

To Whom It May Concern

Re: **ADIPEC 2014 Conference**
"Challenges And Opportunities For The Next 30 Years"
10-13 November 2014, Abu Dhabi, UAE

Dear Sir/Madam,

We are pleased to confirm that **Hossein Ali Akhlaghi Amiri** has been selected to present the paper, **A Prediction Method For Sodium Silicate Gelation Time Under Reservoir Conditions Applied For Water Management** in **Academia Session 2: Field Development** at the 2014 ADIPEC Conference.

Please do not hesitate to contact us should you require any additional information.

Kind regards

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10-13 November
Abu Dhabi International Petroleum Exhibition & Conference
CHALLENGES AND OPPORTUNITIES FOR THE NEXT 30 YEARS
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A Prediction Method For Sodium Silicate Gelation Time Under Reservoir Conditions Applied For Water Management

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Universitetet i Stavanger

Society of Petroleum Engineers

Outlines

- ✓ Introduction
- ✓ Objective
- ✓ Results and discussion
- ✓ Conclusion

Introduction

Water Conformance Control

The major issue in water-flooded oil reservoirs

Challenges

Poor sweep efficiency and excessive water production

The main causes

Reservoir heterogeneities, e.g., high permeability layers

Remedy

Water conformance control methods:

- Mechanical methods
- Chemical methods
  - Near wellbore treatment
  - In-depth treatment

Introduction

Primary requirements for applied gel system

The injected chemi

Alkaline Sodium Silicate

- be able to flow deep into the reservoir along water path

Water-like viscosity prior to gelation

- be injected in large amount

Inexpensive

- be safe for the environment

Environmentally friendly

- plug the desired distance within the reservoir

Controllable gelation time

- withstand high temperature of the reservoir

Thermally stable

Introduction

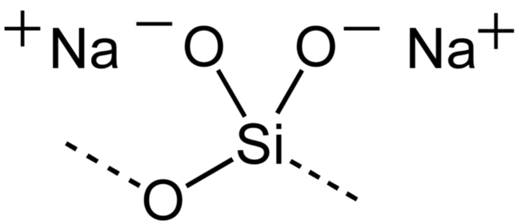
Sodium silicate (Na-silicate) gel system

Was first proposed for reservoir profile modifications by Mills (1922).

Widely applied in reservoir treatments (mostly near wellbore), especially in the North Sea, e.g. Statfjord and recently Snorre.

$$(SiO_2)_n Na_2O$$

$n = 3.35$



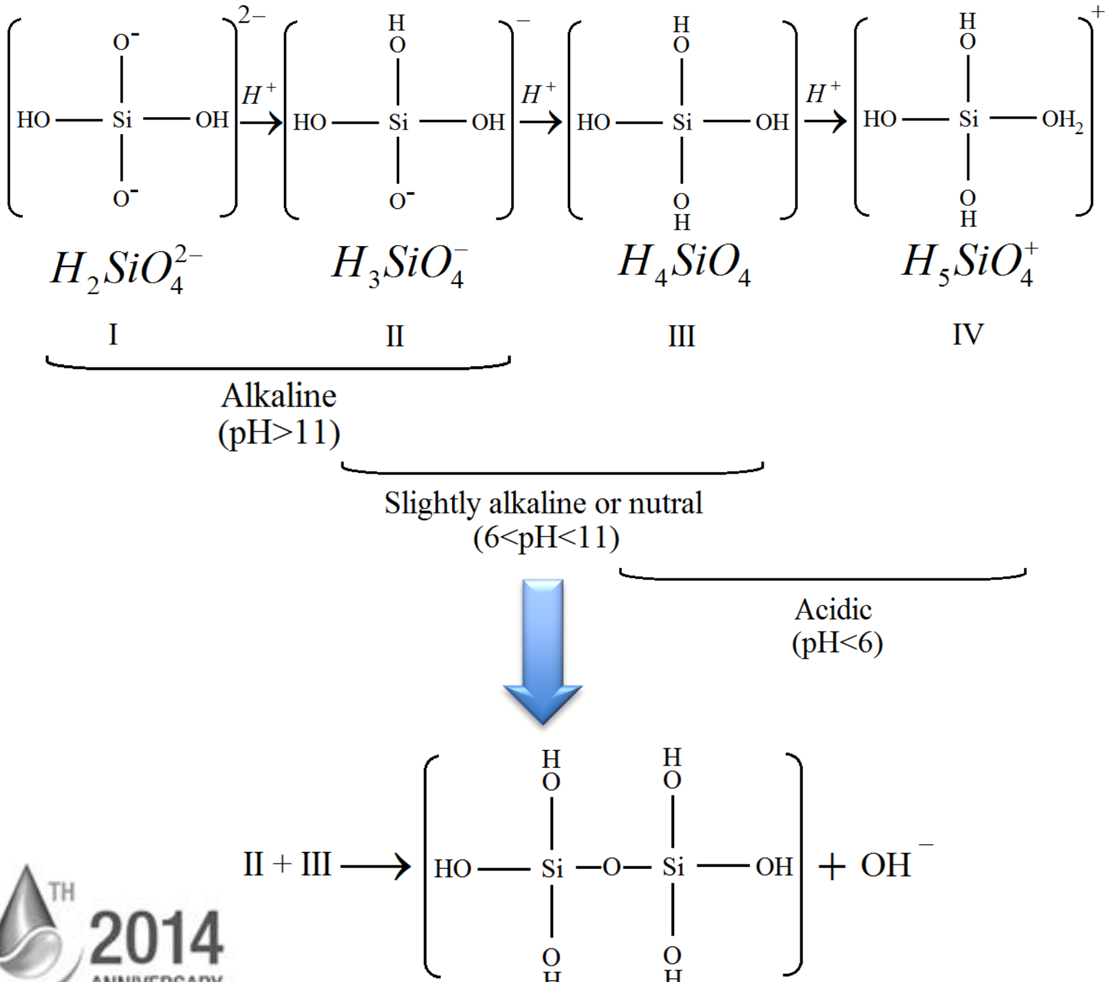
Structure of silicate monomer

Monomers and dimers may aggregate by addition of acid or inorganic salts.

Introduction

Sodium silicate (Na-silicate) gel system

Silicic acid species in Na-silicate solution after addition of acid



$$(OH)_3Si-O-Si(OH)_3$$ Siloxane

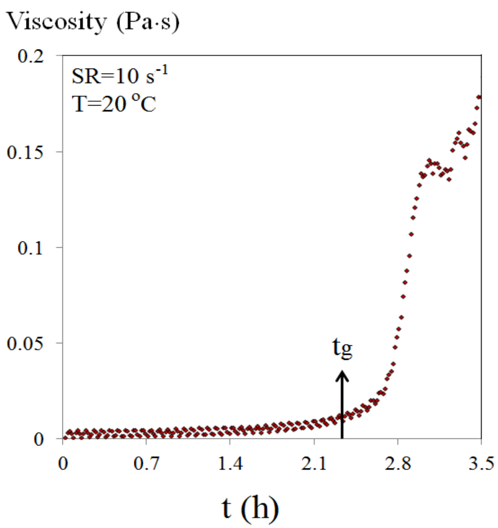
Objective

To investigate alkaline Na-silicate gel system for application as a water conformance control method. Since placement of the chemical is dependent on its gelation kinetics:

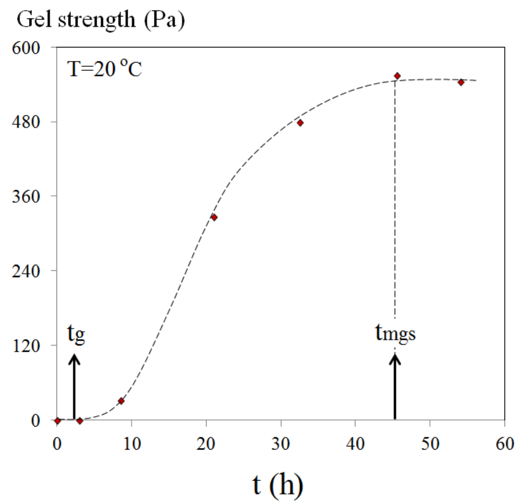
- ✓The main factors which affect Na-silicate gelation kinetics are addressed using accurate bulk measurements (rheological measurements).
- ✓ It is tried to enable predicting the gel setting time under reservoir conditions, e.g., temperature, salinity ….

Results & Discussion

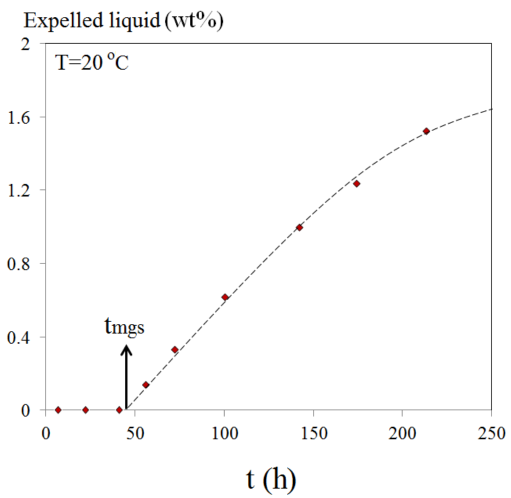
Gelation kinetics



Gel time



Gel strength

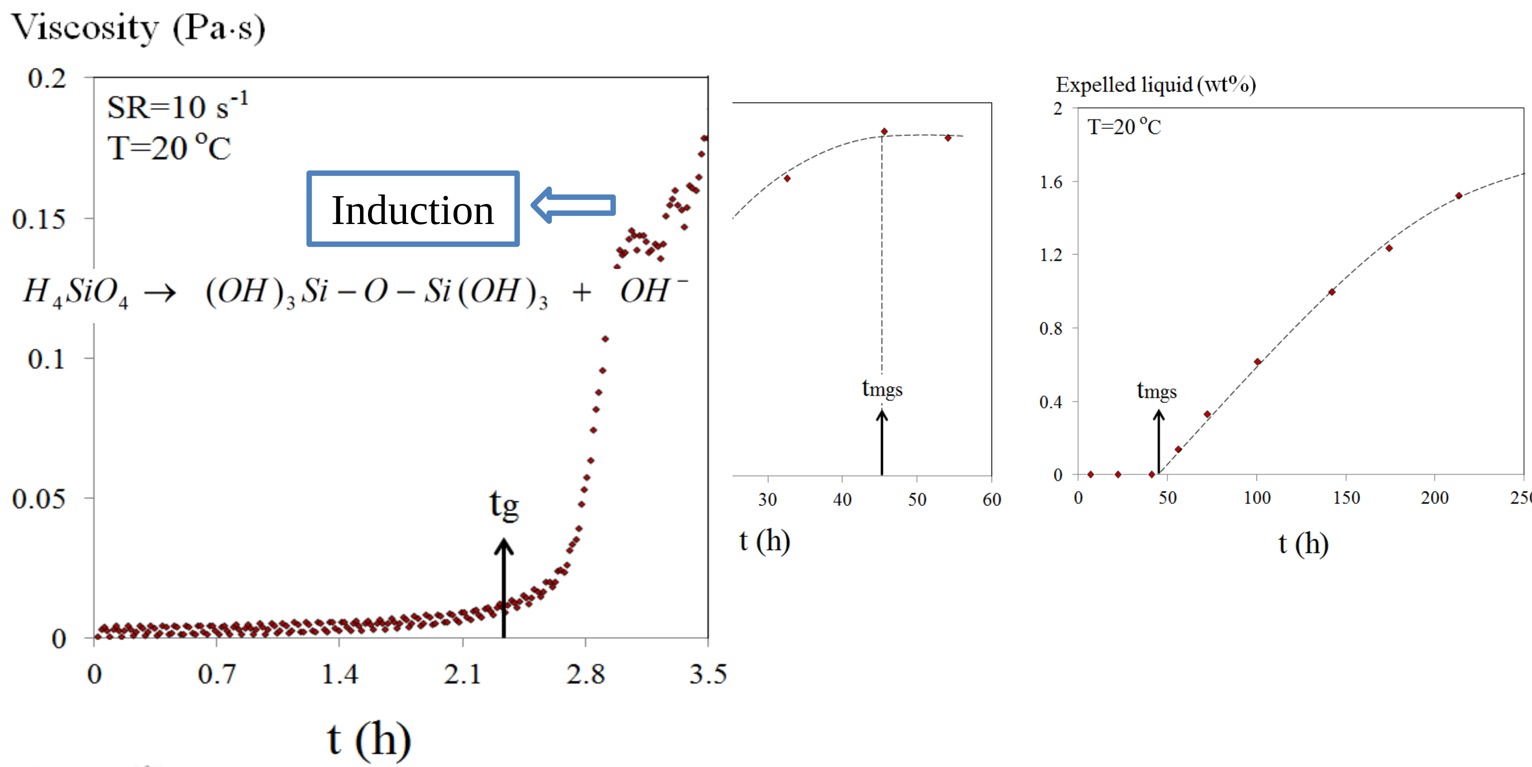


Gel shrinkage

4.5 wt% Na-silicate, pH 10.30, at T=20 °C and zero salinity.

Results & Discussion

Gelation kinetics



$$H_3SiO_4^- + H_4SiO_4 \rightarrow (OH)_3Si-O-Si(OH)_3 + OH^-$$

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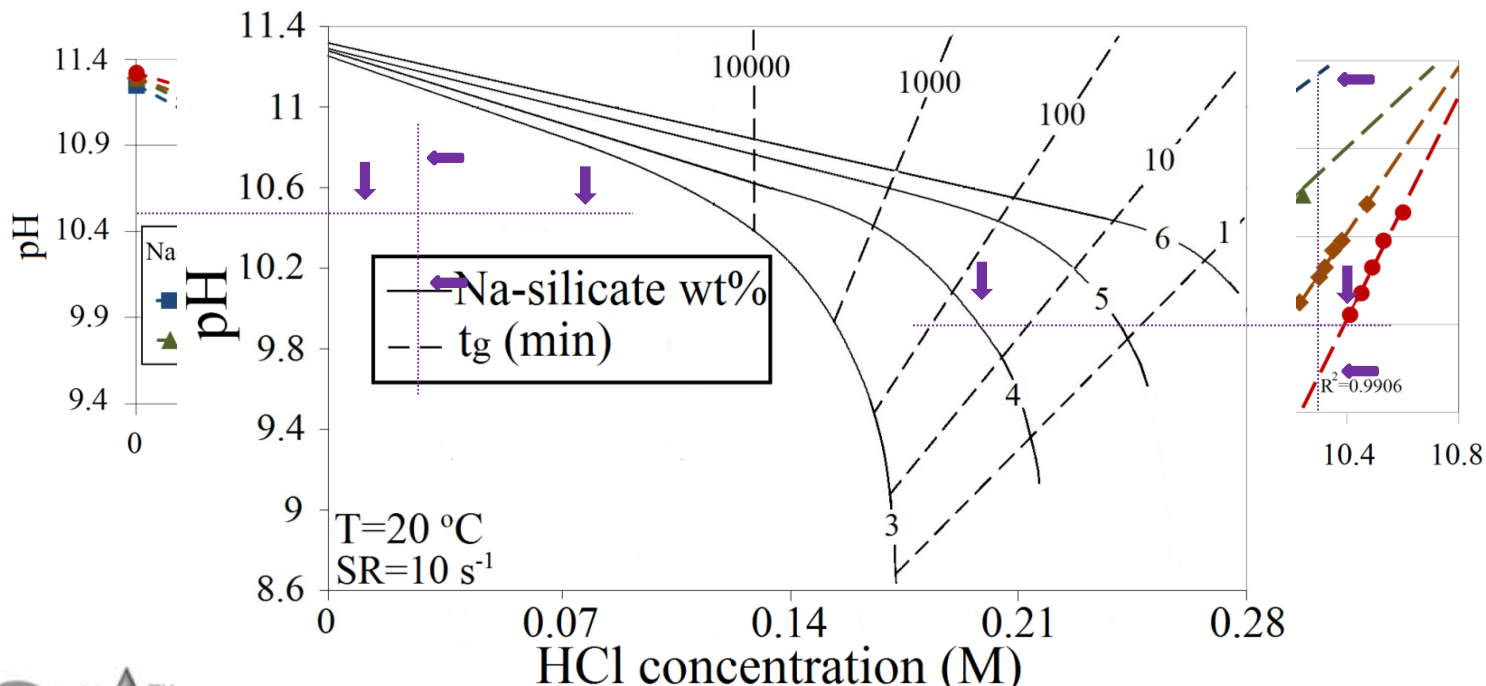
Results & Discussion

Gelation kinetics

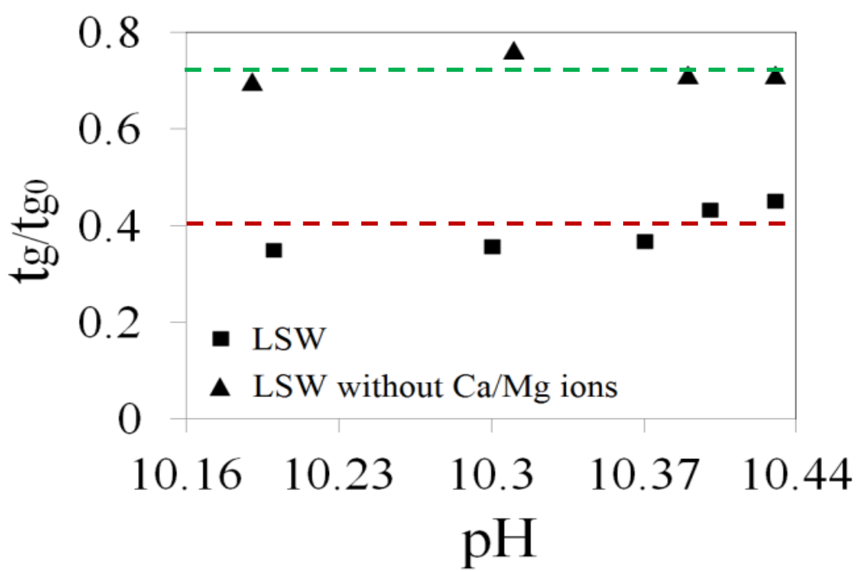
Effects of Na-silicate content and pH



Results & Discussion

Gelation kinetics

Effect of salinity



4.5 wt% Na-silicate at T=20 °C

t_{g0}= gel time at zero salinity and room temperature

LSW: 25-time diluted synthetic sea water

Synthetic sea water composition

Component	Concentration (M)
NaCl	0.4
Na_2SO_4	0.024
$NaHCO_3$	0.002
KCl	0.01
$MgCl_2$	0.044
$CaCl_2$	0.013
Total	0.495

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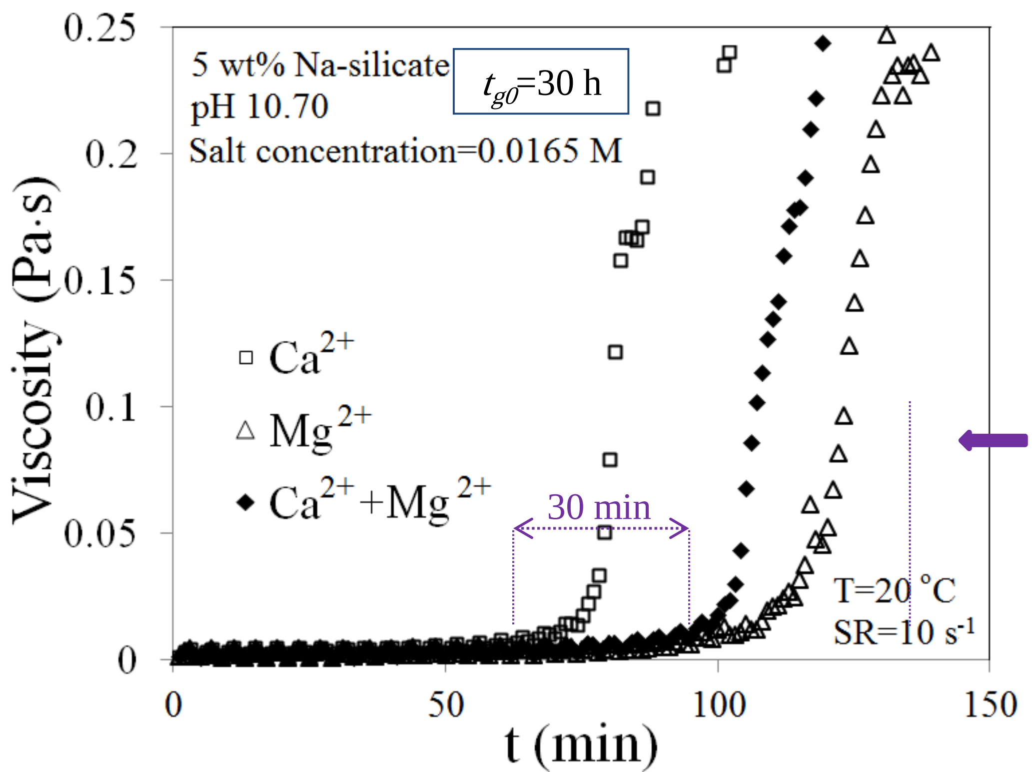
Results & Discussion

Gelation kinetics

Effect of divalent ions



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t_{g0}= gel time at zero salinity and room temperature

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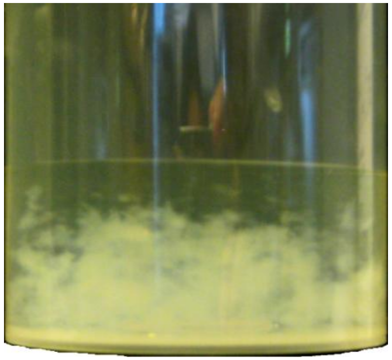
Results & Discussion

Precipitation

Effect of divalent ions



Adding 25wt% sea water in
4.5 wt% Na-silicate solution

$$2\,(\equiv SiO^{-}Na^{+}) + MgCl_2 \rightarrow 2 \equiv SiO^{-}Mg^{2+} + 2NaCl$$

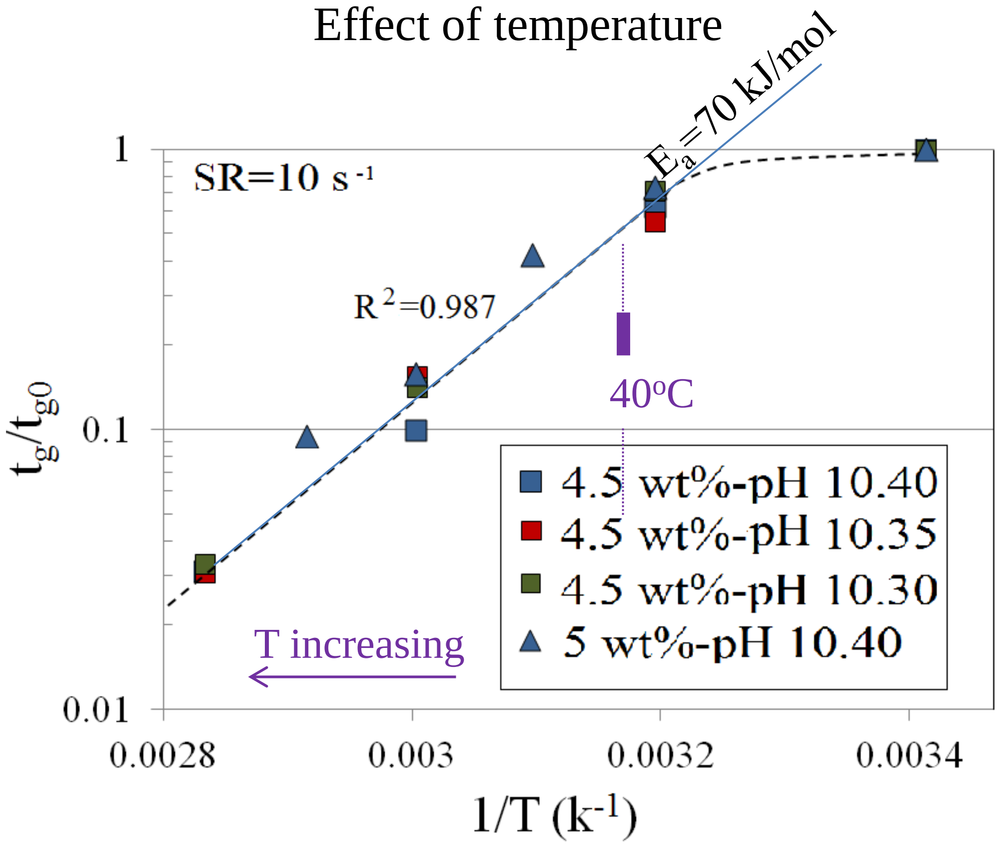
$$2\,(\equiv SiO^{-}Na^{+}) + CaCl_2 \rightarrow 2 \equiv SiO^{-}Ca^{2+} + 2NaCl$$

Na-silicate solutions prepared with 20 times diluted SW showed no precipitation.

Results & Discussion

Gelation kinetics

Effect of temperature



Modified Arrhenius equation: $$t_g = Ae^{E_a/RT}$$

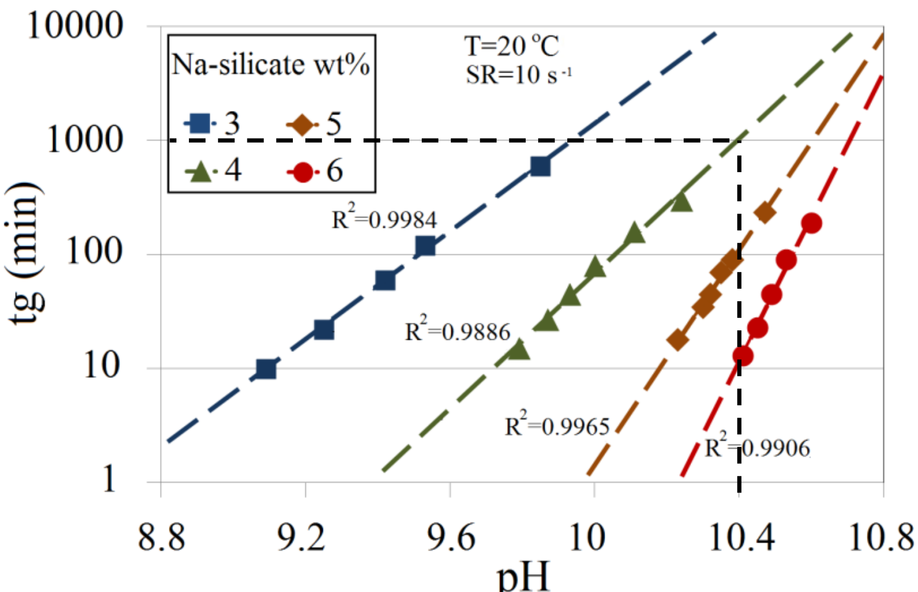
Results & Discussion

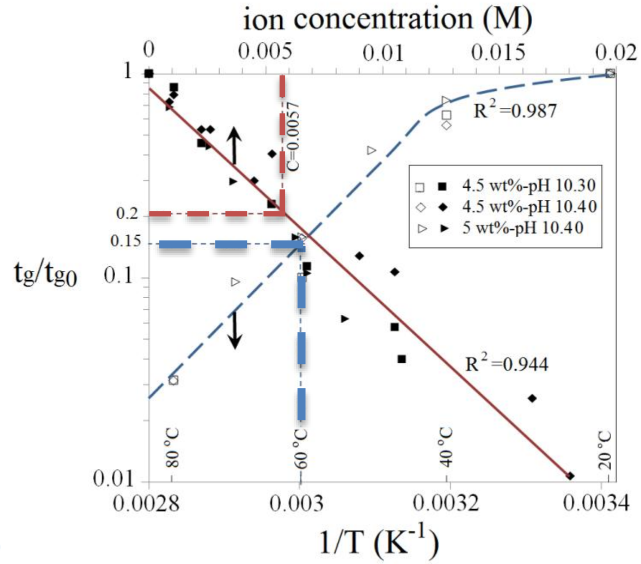
Gelation kinetics

Prediction method

Na-silicate (wt%)	pH	T (°C)	$CaCl_2$ (ppm)	$MgCl_2$ (ppm)
4	10.40	60	400	200

1/T=0.003 1/K   ion concentration=0.0057 M





$$t_{g0} = 1000\,\text{min}$$

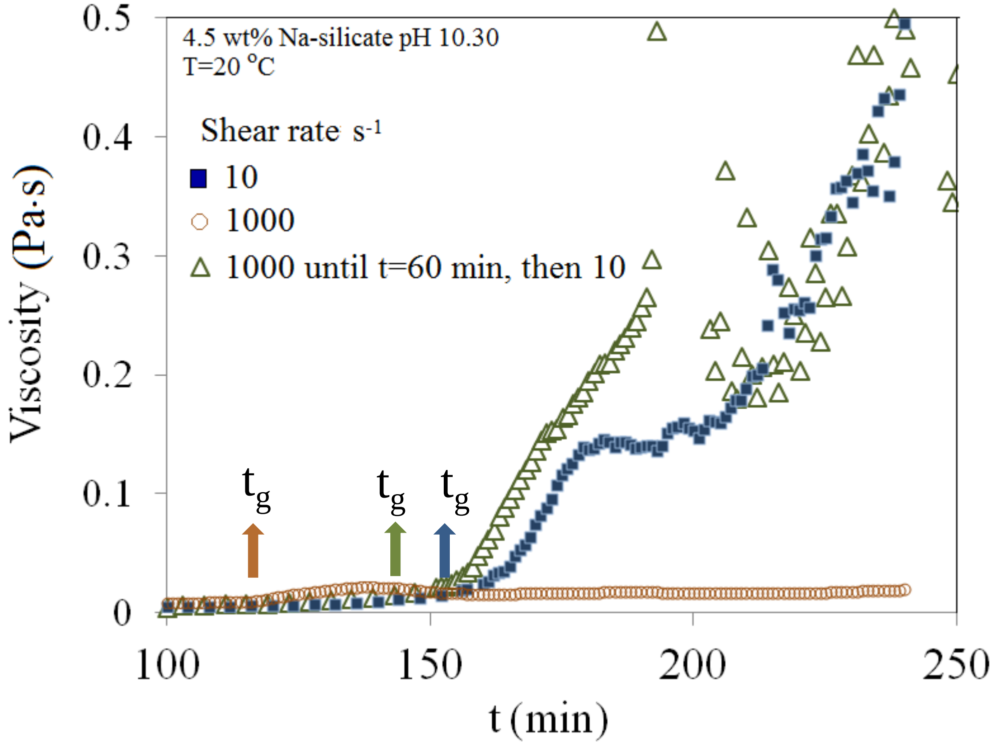
$$t_g = t_{g0} \times \left(\frac{t_g}{t_{g0}}\right)_T \times \left(\frac{t_g}{t_{g0}}\right)_{ion} = 1000 \times 0.15 \times 0.2 = 30\,\text{min}$$

Experimental value= 33 min

Results & Discussion

Na-silicate gelation rheology

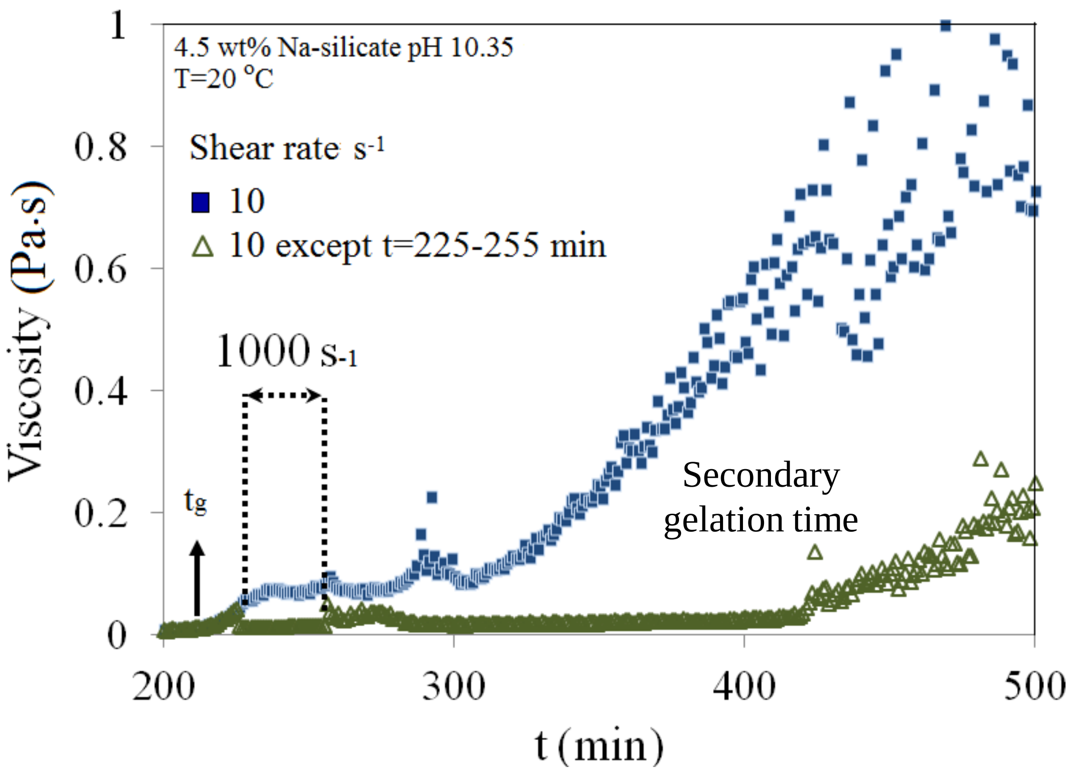
Effect of high shear rate before gelation time



Results & Discussion

Na-silicate gelation rheology

Effect of high shear rate after gelation time



Conclusions

- Na-silicate shows water-like viscosity prior to gelation, i.e., good injectivity into the reservoir.
- Na-silicate content, pH, formation water salinity (especially divalent cations) and temperature affect Na-silicate gelation kinetics.
- A simple graphical method was suggested to roughly estimate the combined effects of different factors on the gel time.
- Metal silicate precipitation is not observed in the case of mixing Na-silicate with LSW (25-fold diluted sea water). LSW is a option for pre-flushing in the field applications.
- Imposing temporary high shear rates before the gel time (high shear rate in the wellbore area) accelerates the setting time and must be considered in field applications.

Publications

H. A. Akhlaghi Amiri, A. A. Hamouda, 2014: Factors affecting alkaline sodium silicate gelation for in-depth reservoir profile modification. *Energies* 7(2), 568-590.

H. A. Akhlaghi Amiri, A. A. Hamouda and A. Roostaei, 2014: Sodium silicate behavior in porous media applied for in-depth profile modifications. *Energies* 7 (4), 2004-2026.

Acknowledgements

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I would like to express my best appreciation to the University of Stavanger and its staff.

Thanks for your attention

Questions?