Geothermal Utilization: Scaling and Corrosion

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The "good" news

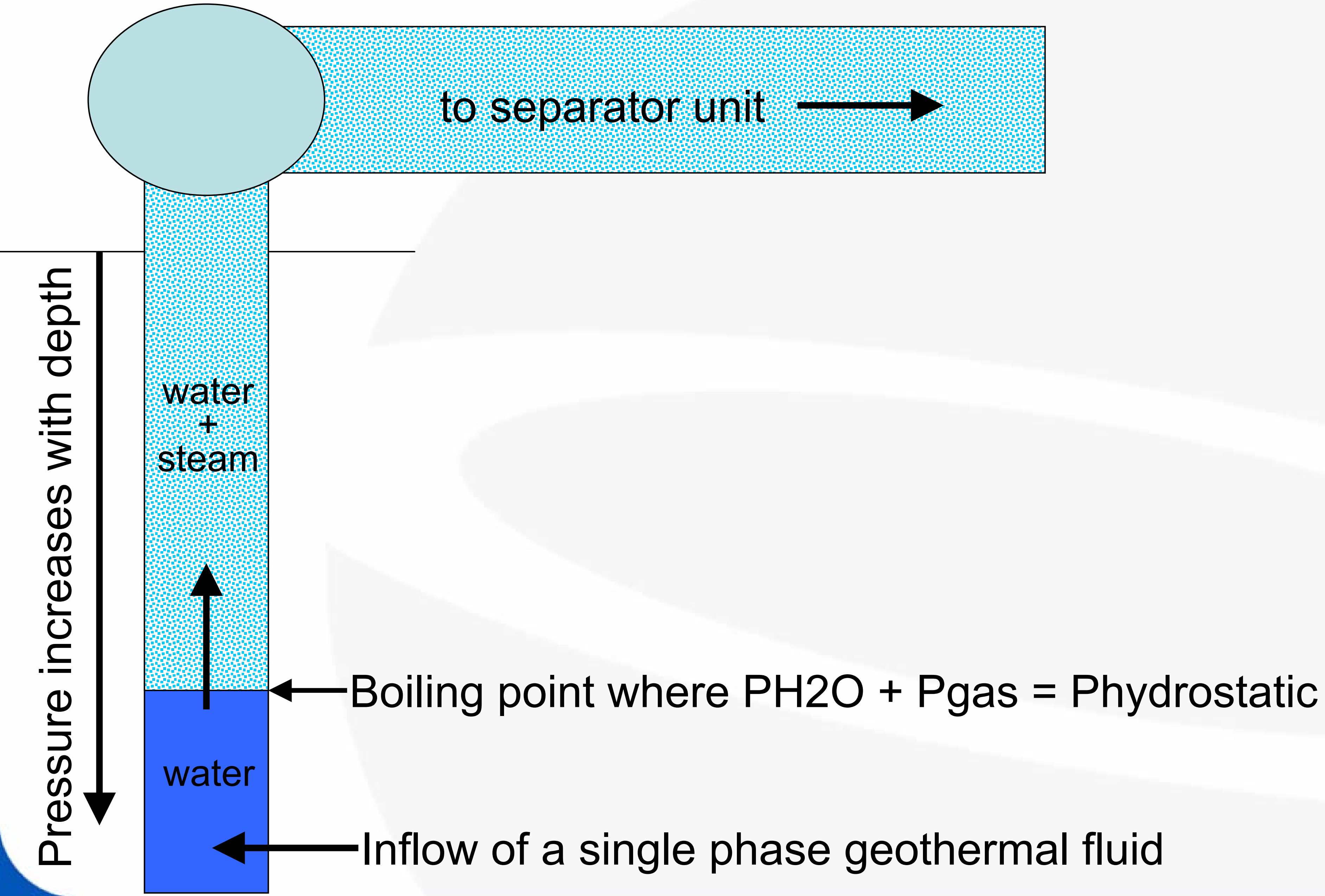
- **Reliability and long life:**
- Reservoirs for >100 years.
- Wells for 20-40 years.
- Plant equipment 20-50 years.
- High availability.
- **Proven technology:**
- Drilling with repeatable results.
- Conventional plants and binary plants.
- Several fluid handling procedures available against corrosion and scaling.

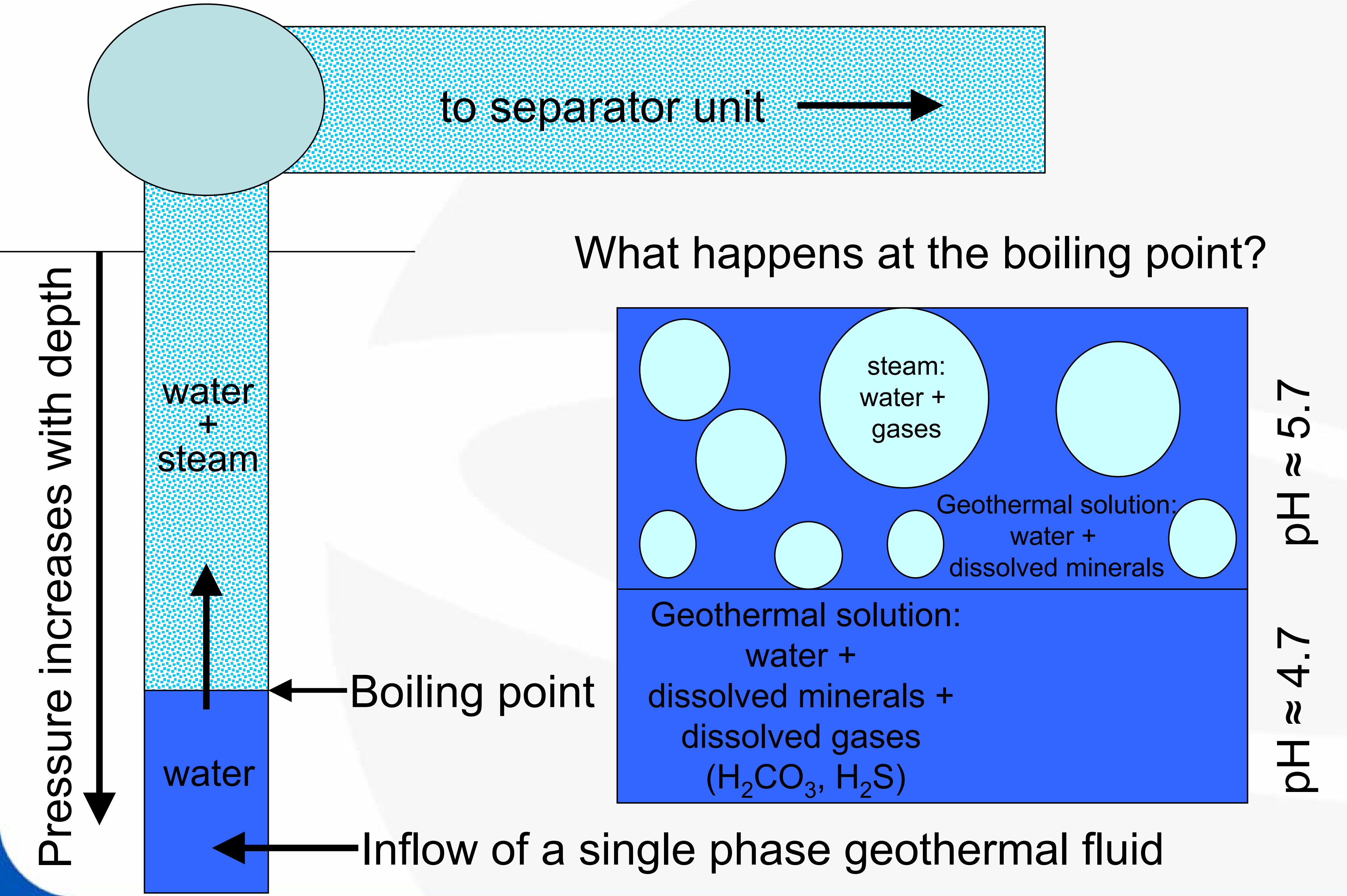
Types of scaling

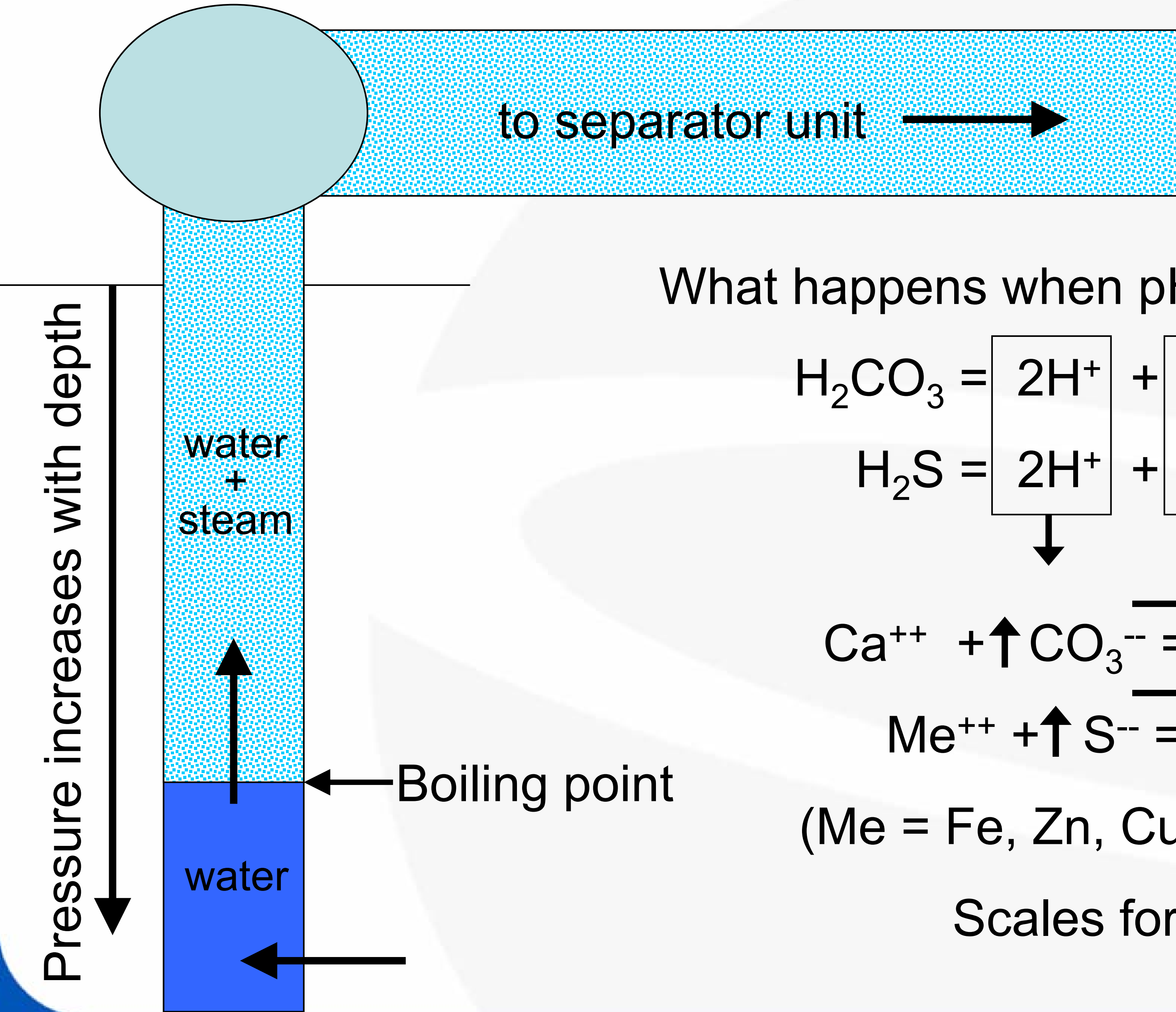
- Boiling point scaling in production wells
  - Calcium carbonate
  - Metal sulfides
- Scaling in surface equipment
  - Mostly amorphous silica
  - Calcium carbonate and sulfides to a lesser degree
- Scaling in reinjection wells
  - Amorphous silica

Boiling point scaling

- Occurs over limited interval in production wells
- Caused by sudden pH changes due to boiling
- Involves precipitation of calcium carbonates and metal sulfides
- Problematic where fluids have high TDS or high concentration of dissolved calcium carbonate


to separator unit
Pressure increases with depth
water
+
steam
Boiling point where PH2O + Pgas = Phydrostatic
water
Inflow of a single phase geothermal fluid


to separator unit
What happens at the boiling point?
water
+
steam
Pressure increases with depth
steam:
water +
gases
Geothermal solution:
water +
dissolved minerals
pH ≈ 5.7
Boiling point
Geothermal solution:
water +
dissolved minerals +
dissolved gases
(H_2CO_3, H_2S)
pH ≈ 4.7
water
Inflow of a single phase geothermal fluid



What happens when pH goes up?

$$H_2CO_3 = 2H^+ + CO_3^{--}$$

$$H_2S = 2H^+ + S^{--}$$

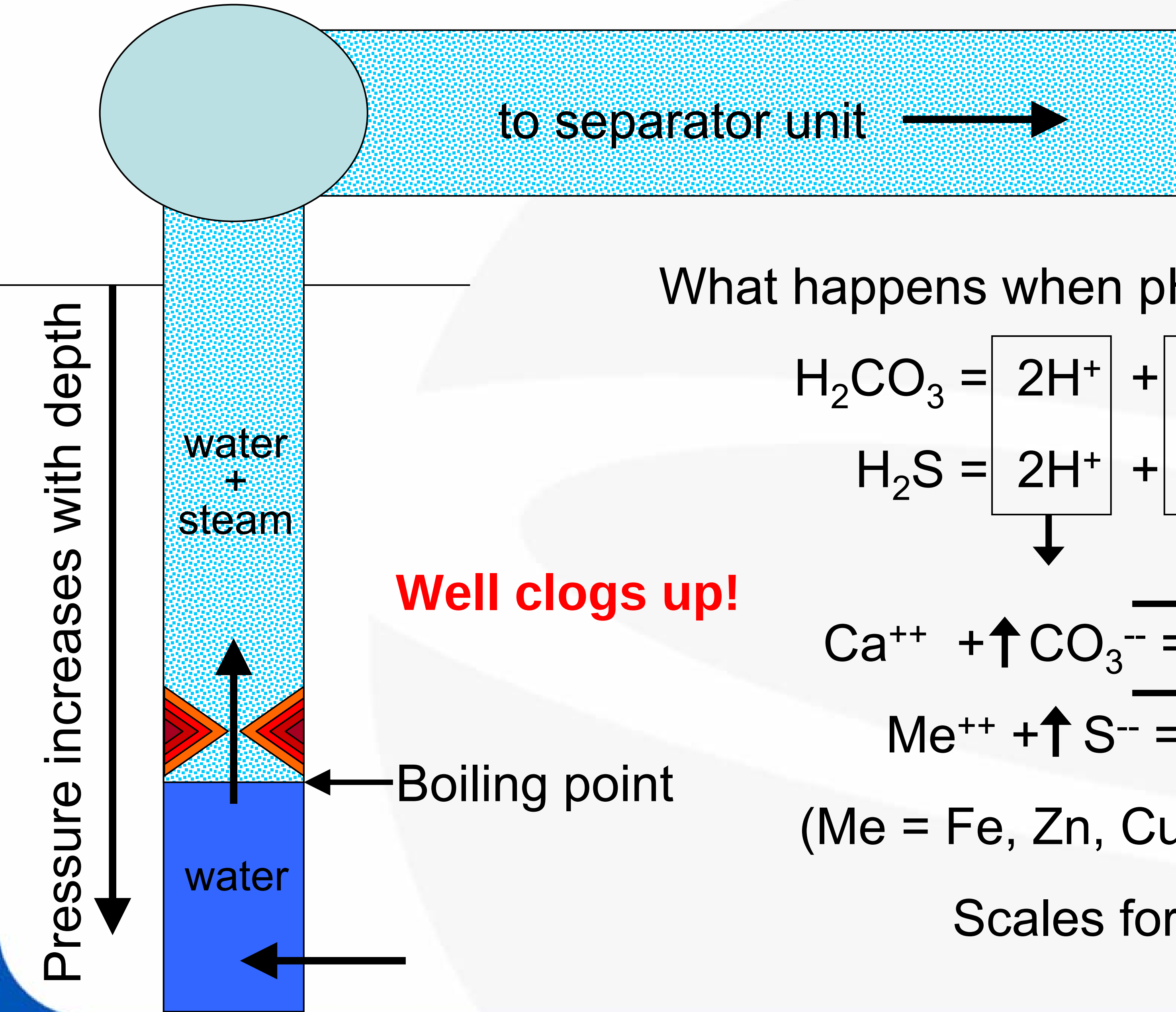
($2H^+$ ↓, CO_3^{--} / S^{--} ↑)

$$Ca^{++} + \uparrow CO_3^{--} \rightarrow CaCO_3$$

$$Me^{++} + \uparrow S^{--} \rightarrow MeS$$

(Me = Fe, Zn, Cu, Pb etc.)

Scales form!



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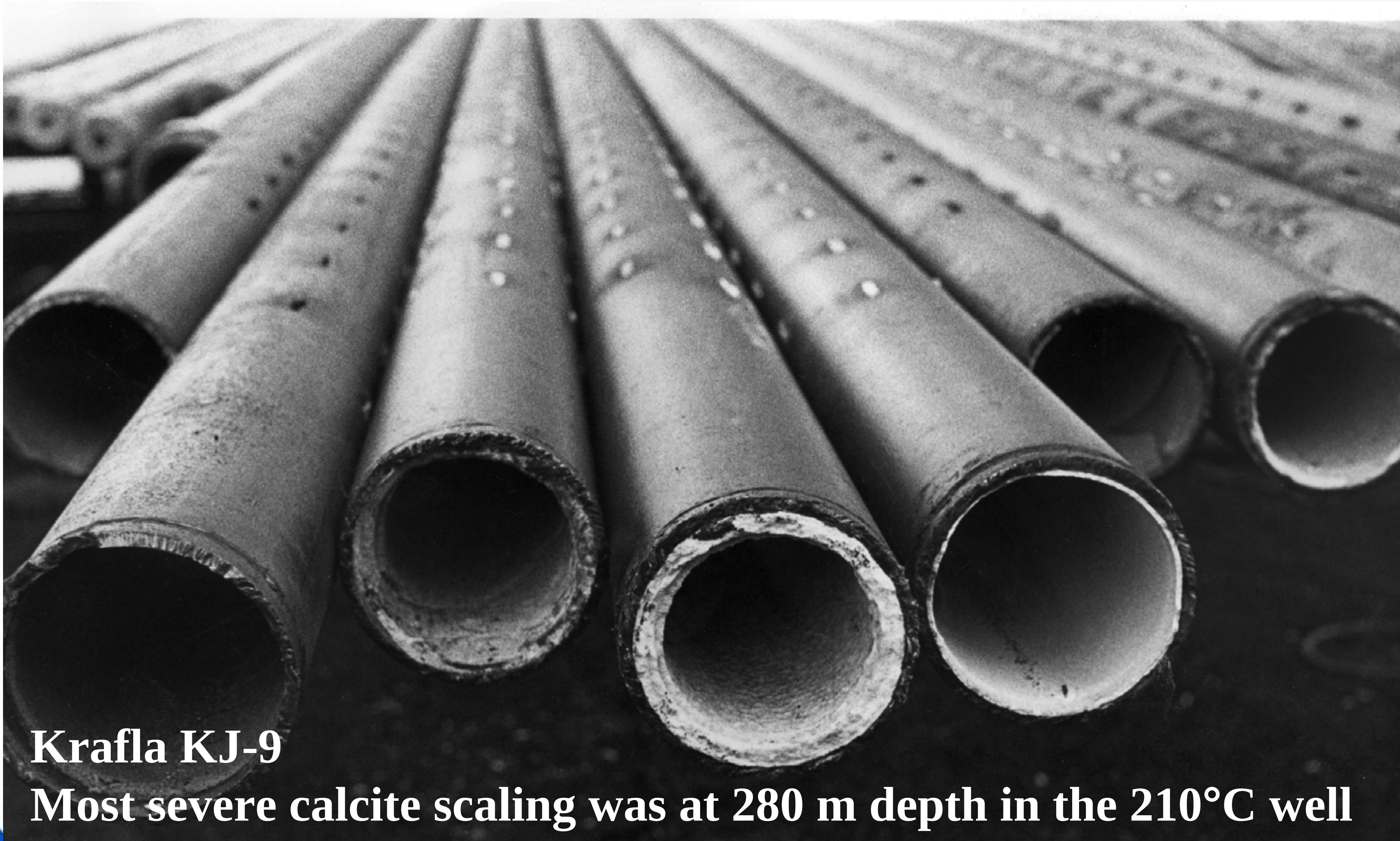
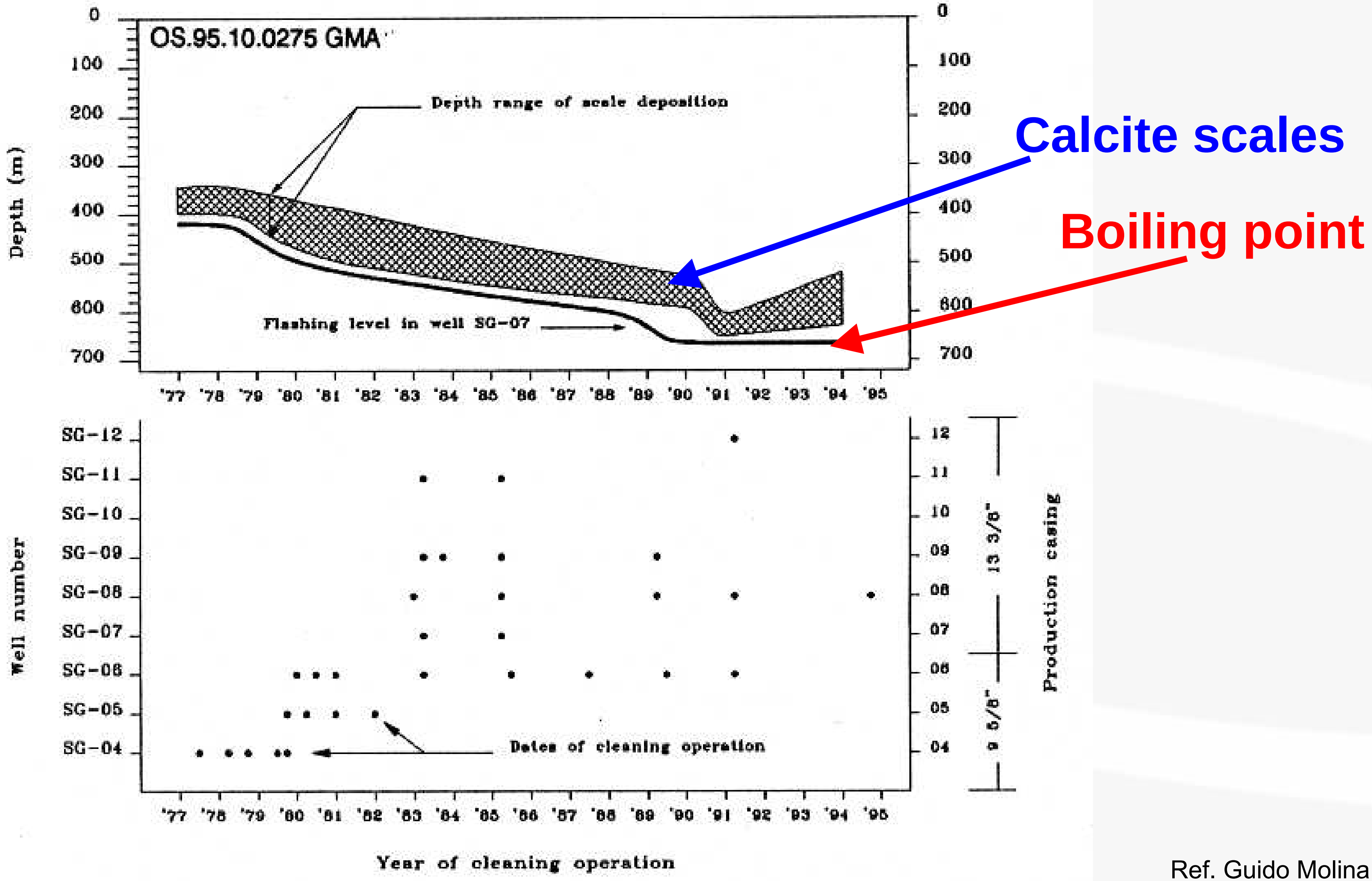
Scales form!

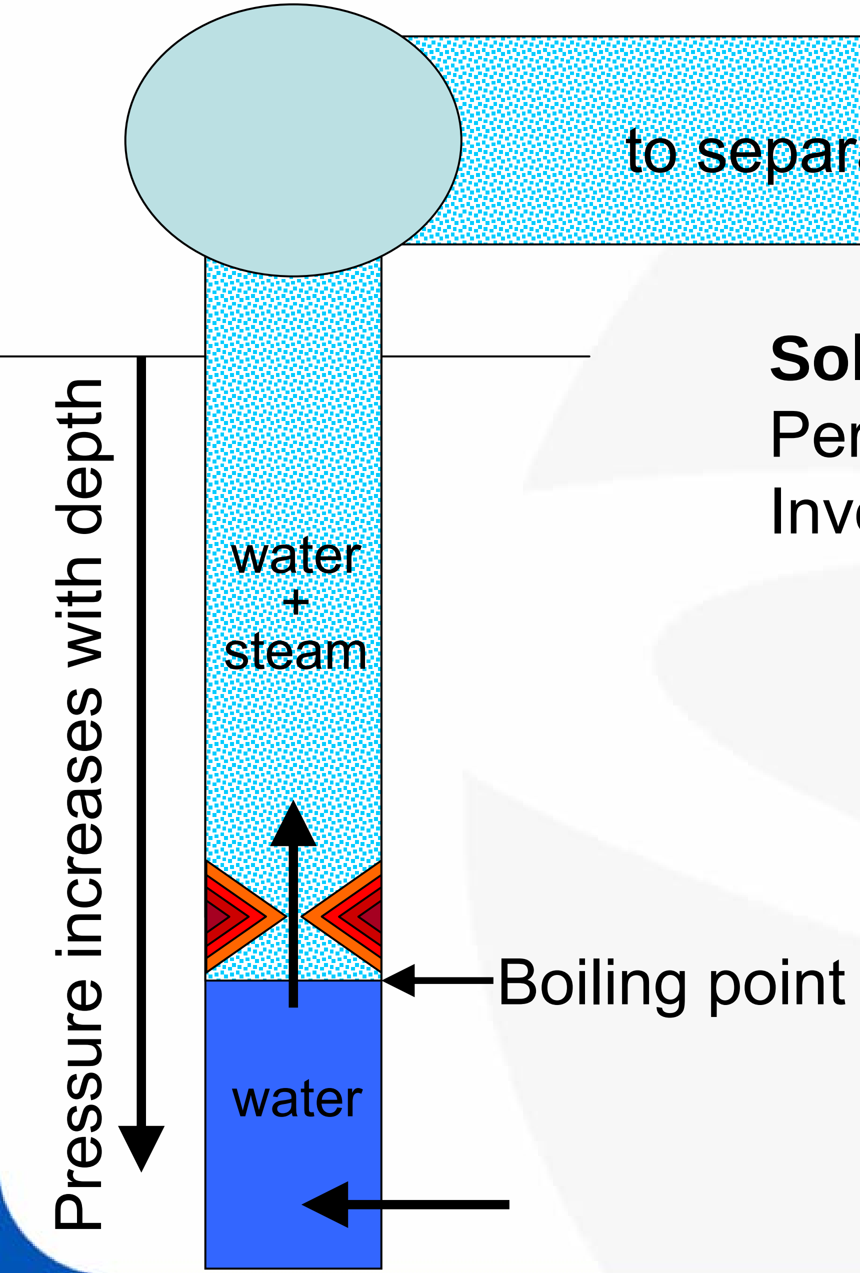
Calcite scaling inside a slotted liner



Calcite scales in Svartsengi field SW Iceland



Ref. Guido Molina



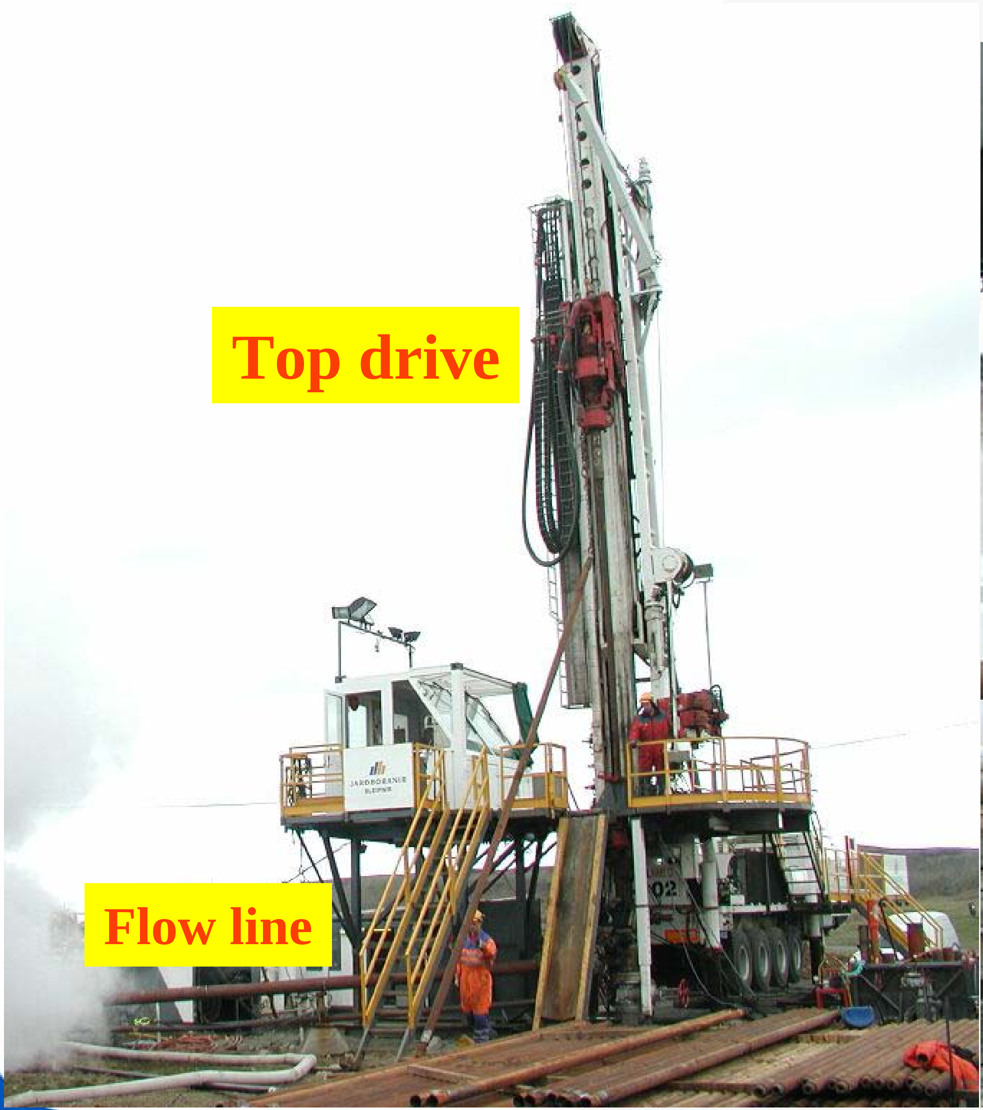
Solution 1

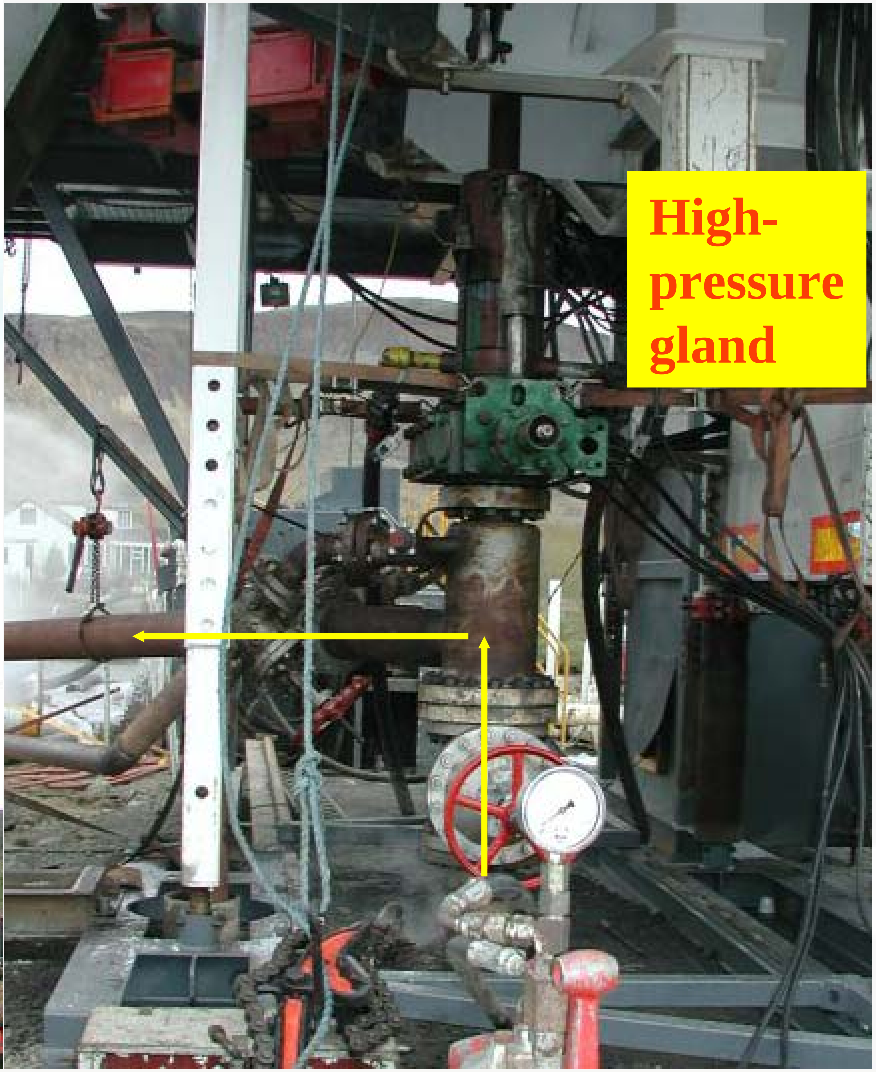
Periodic workover of well

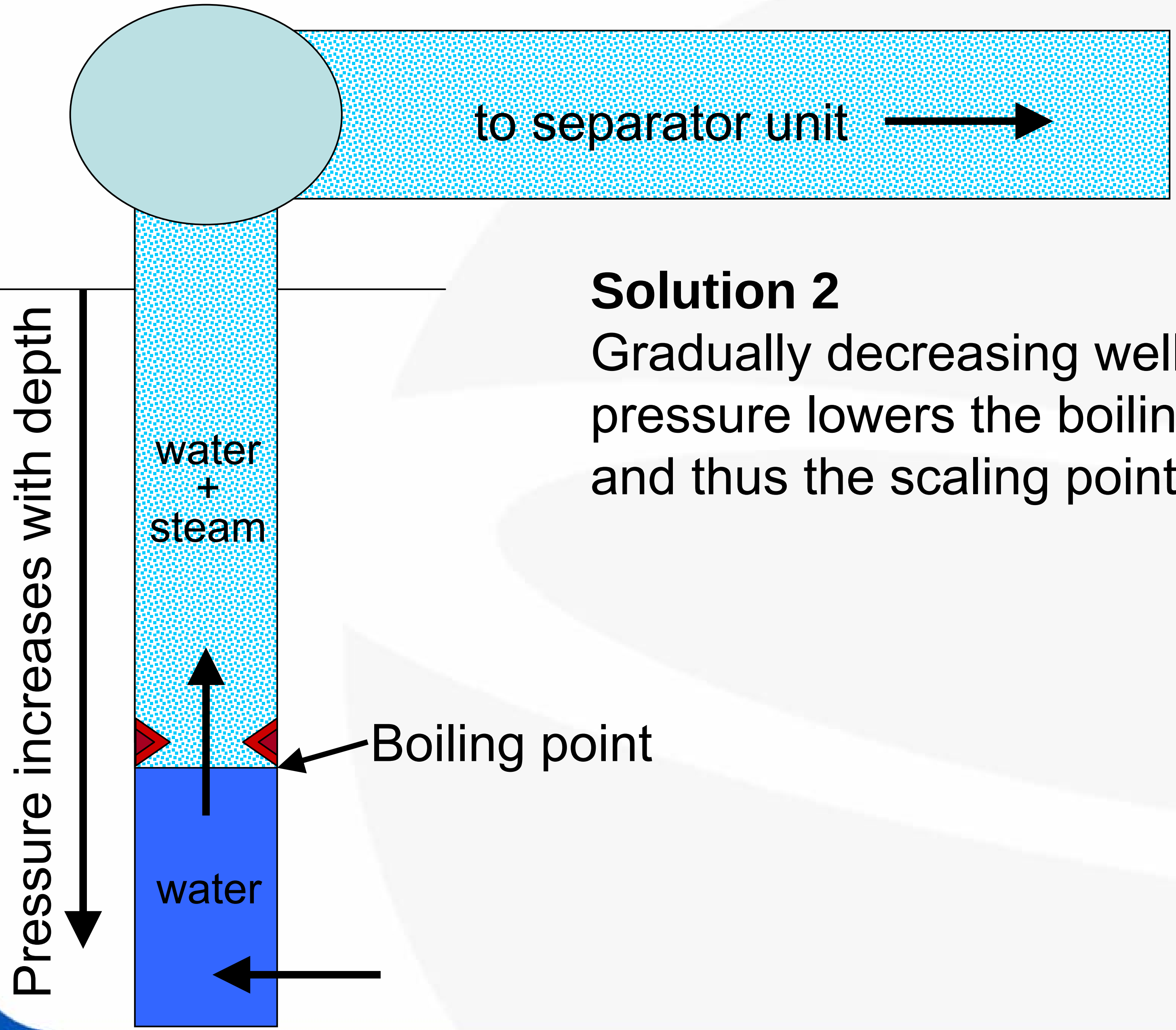
Involving:

- reaming with a rig
- high-pressure washing
- acid cleaning

Reaming of a well while discharging

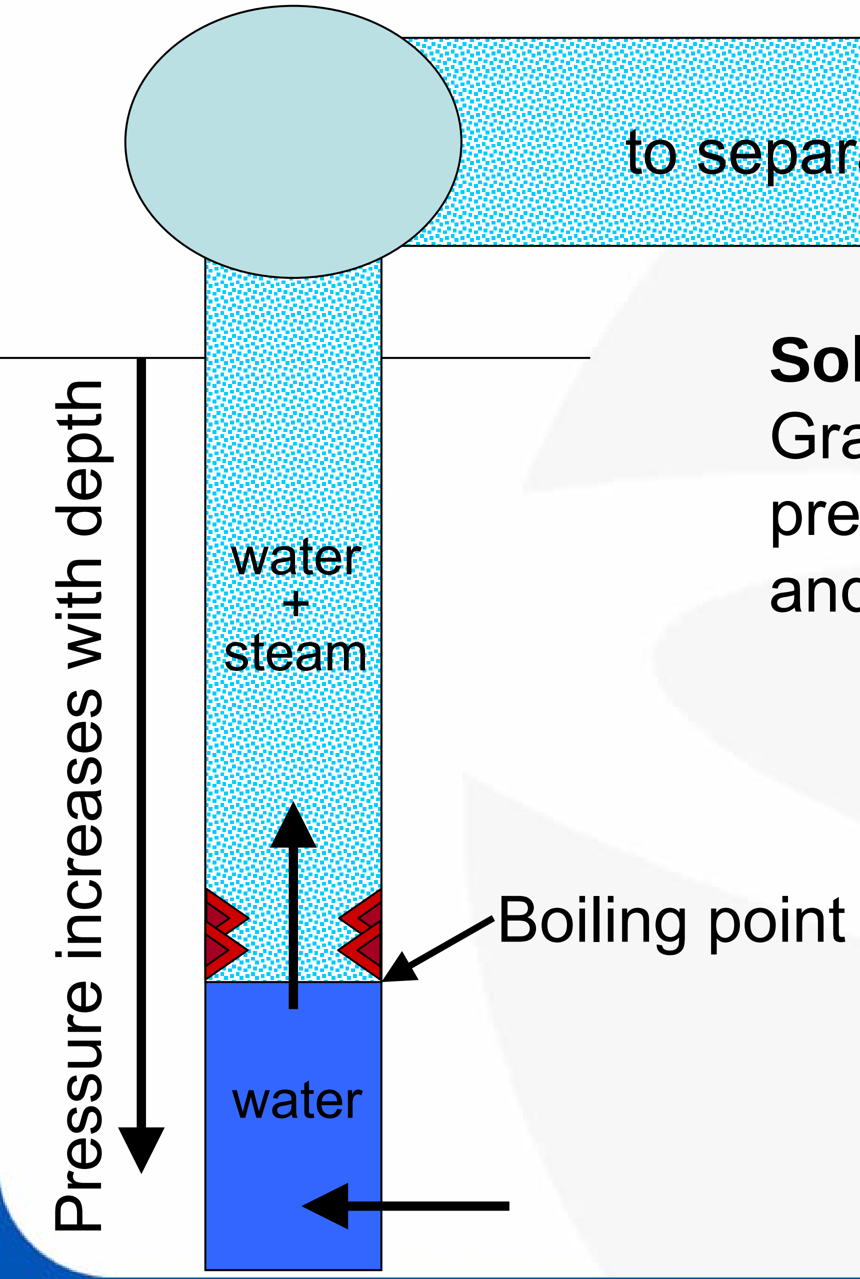






Solution 2

Gradually decreasing wellhead pressure lowers the boiling point and thus the scaling point



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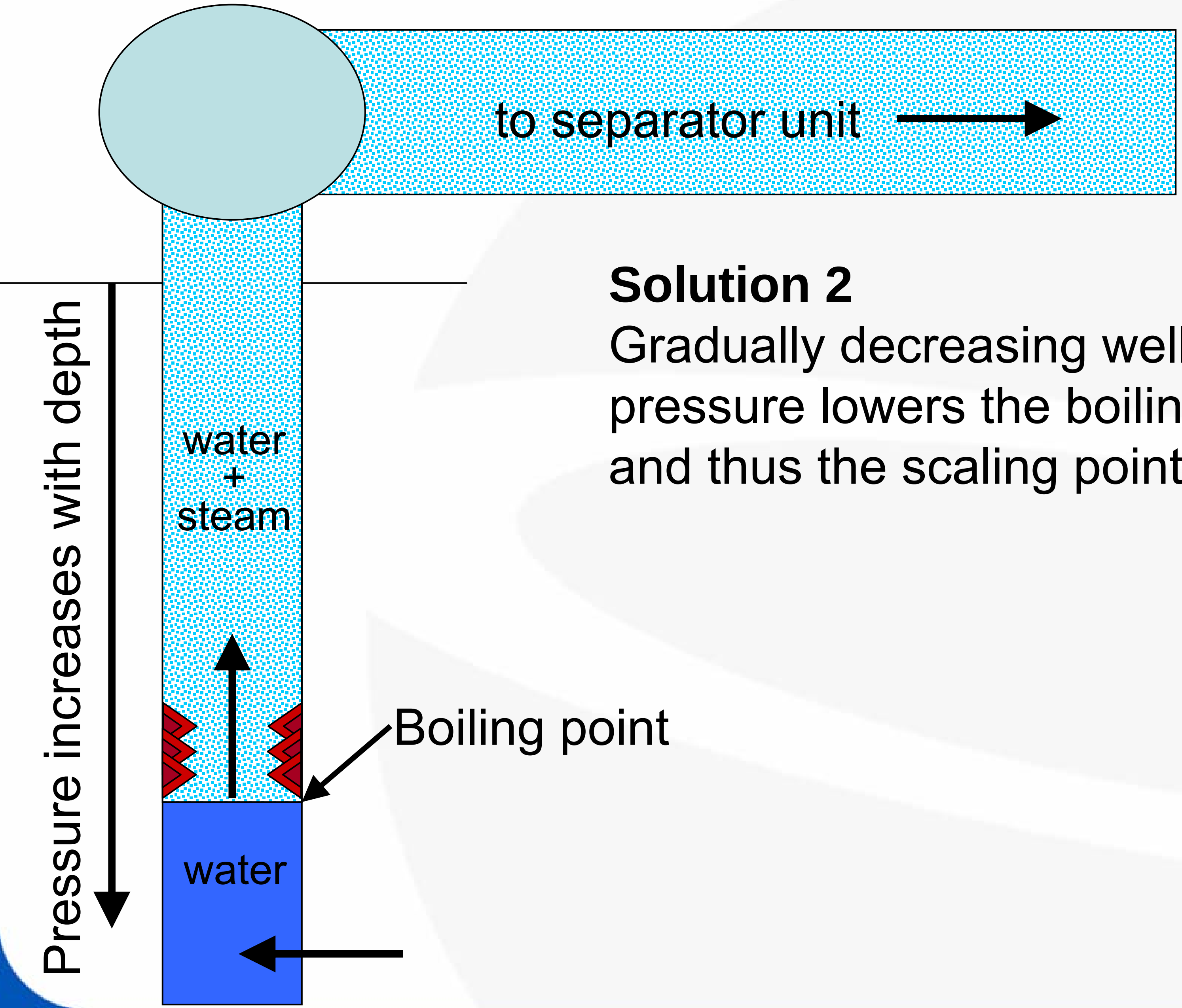

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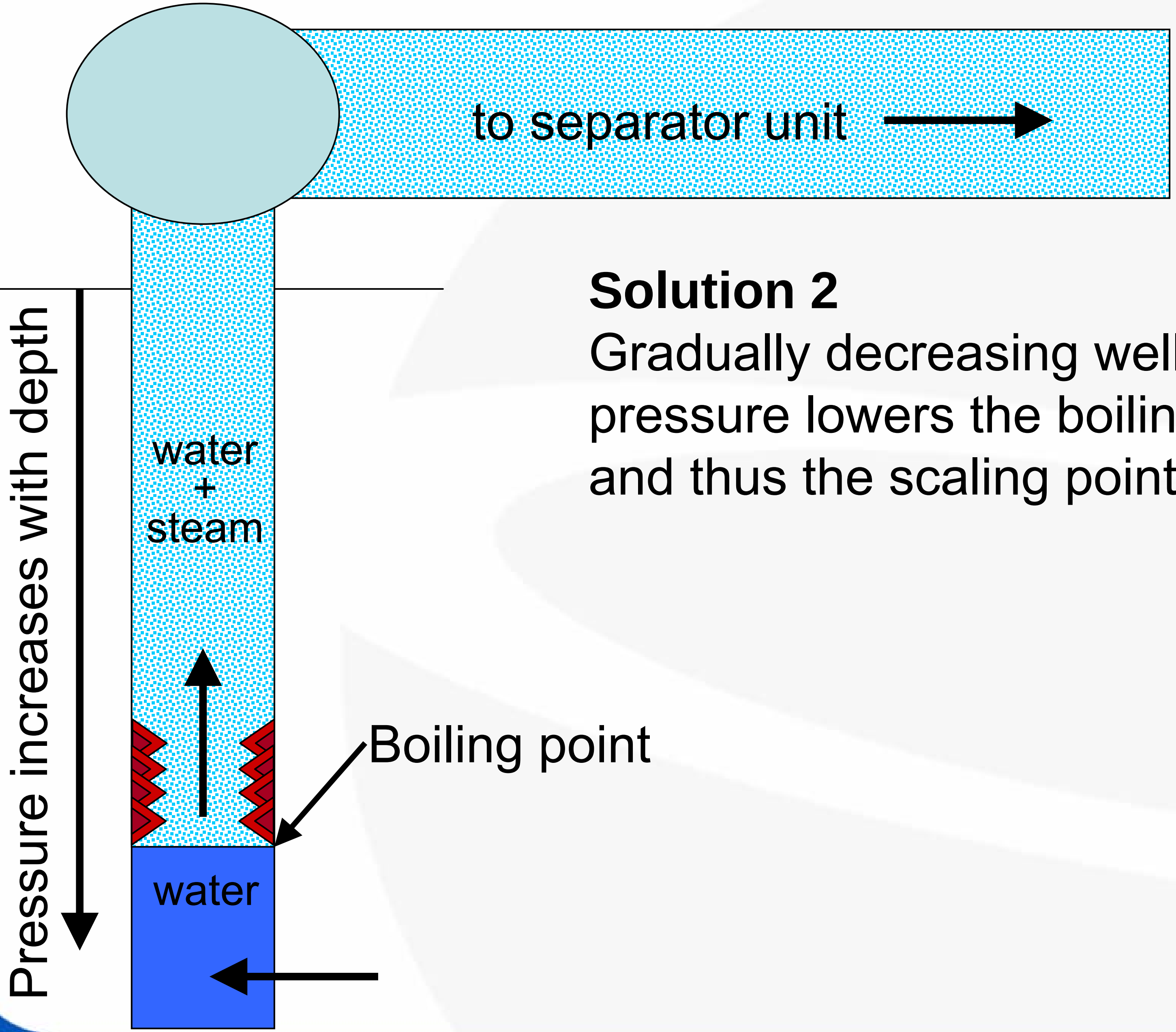

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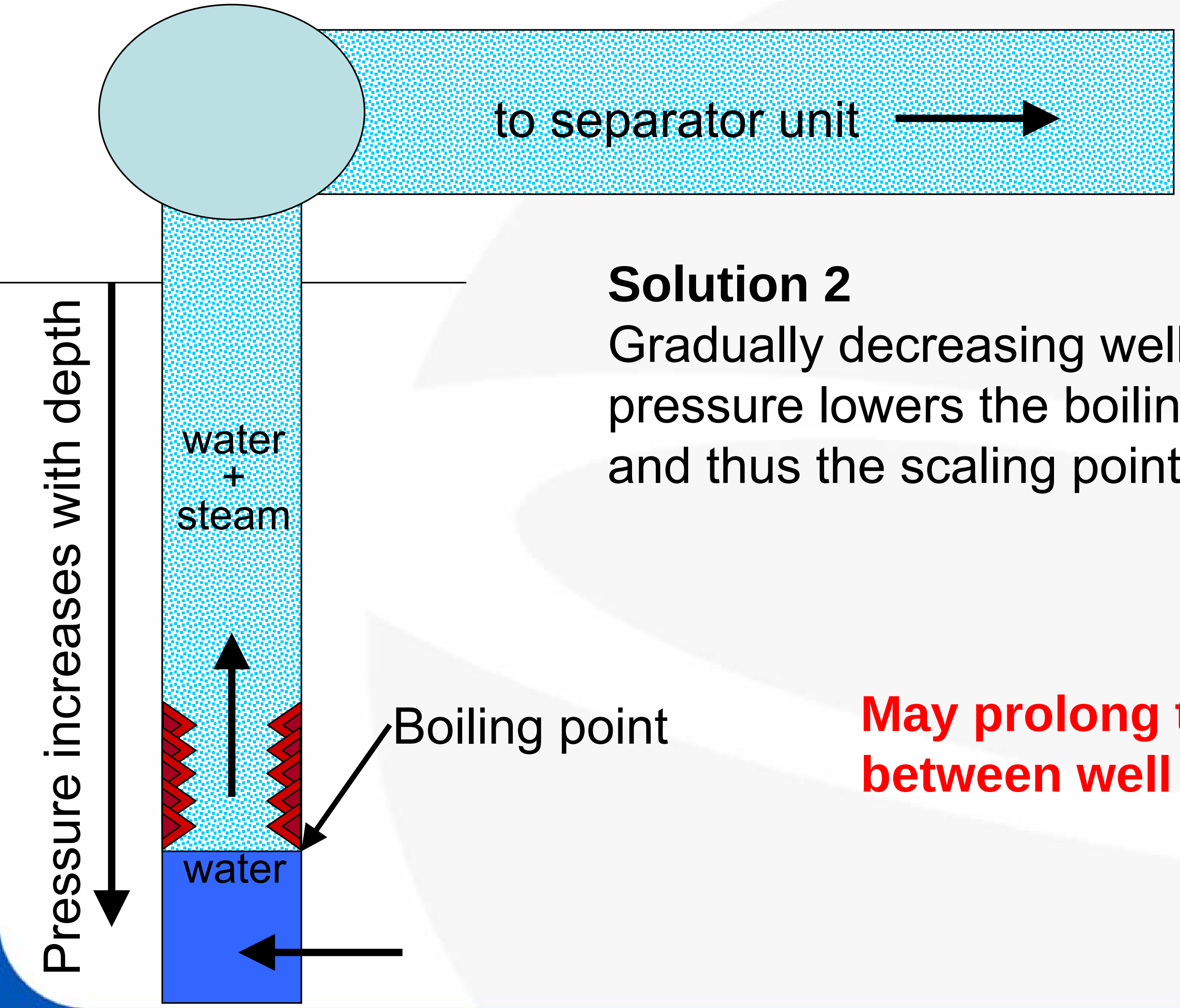
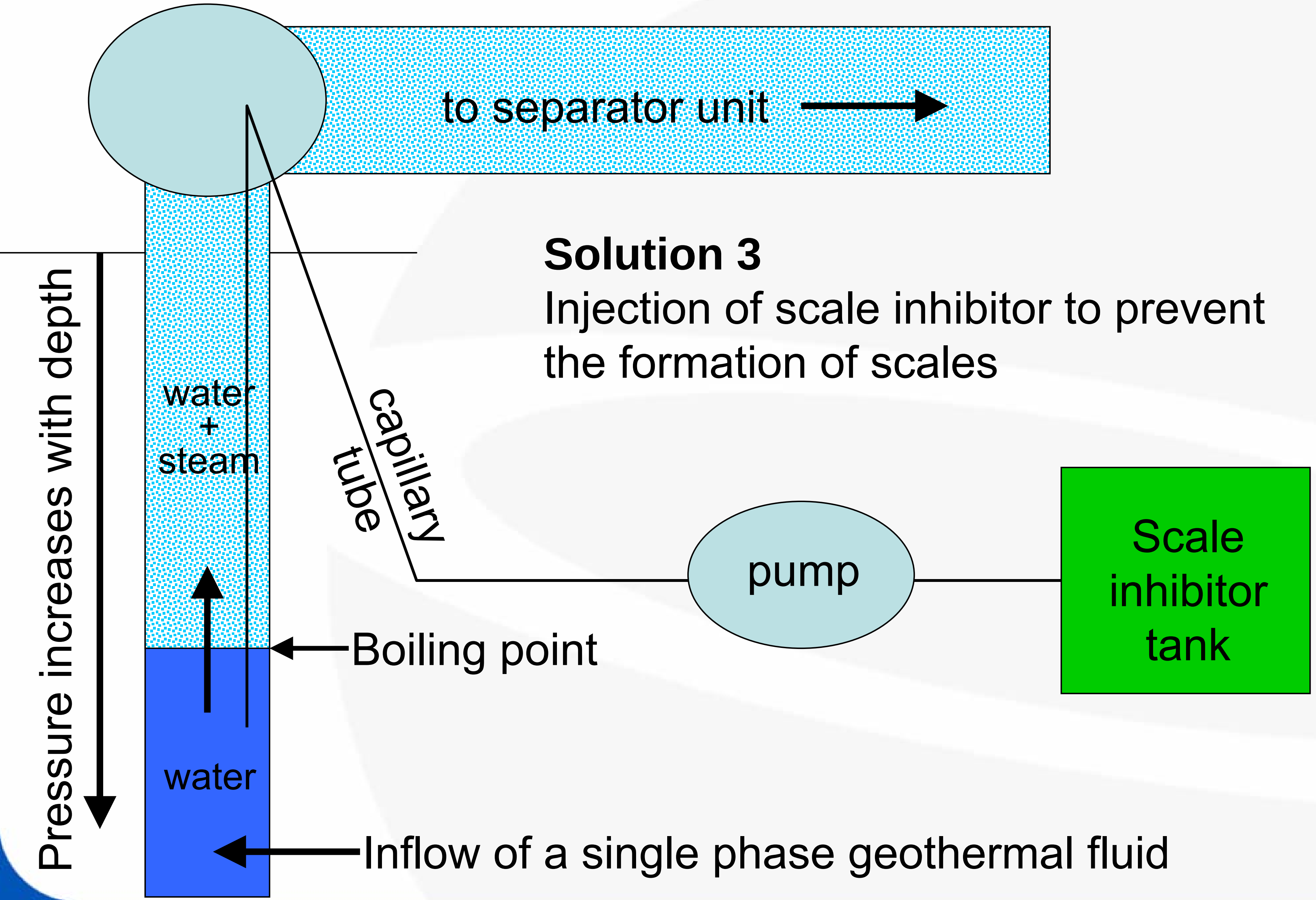


Solution 2
Gradually decreasing wellhead pressure lowers the boiling point and thus the scaling point

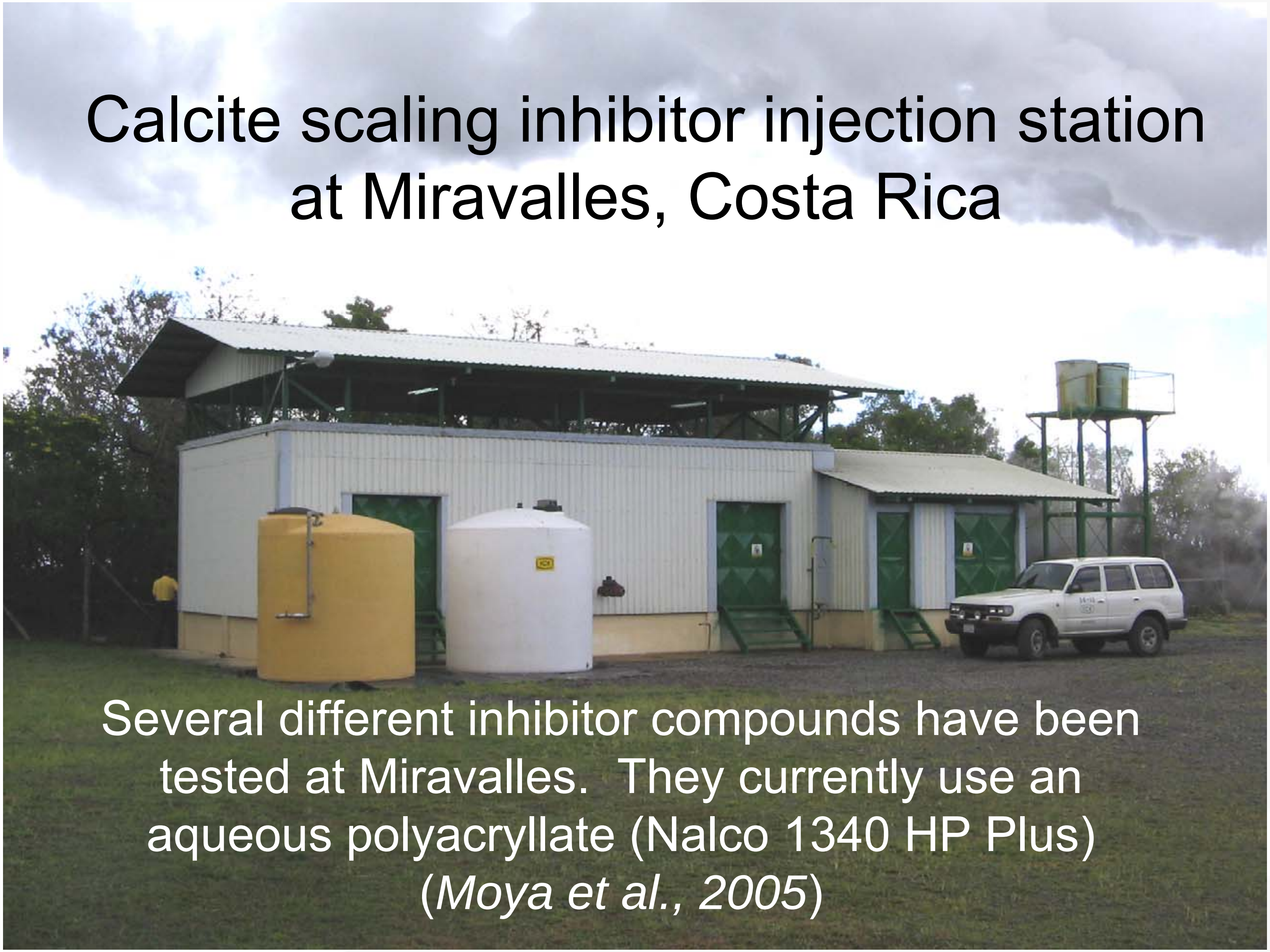
May prolong the interval between well workovers

Solution 3

Injection of scale inhibitor to prevent the formation of scales



Calcite scaling inhibitor injection station at Miravalles, Costa Rica



Several different inhibitor compounds have been tested at Miravalles. They currently use an aqueous polyacryllate (Nalco 1340 HP Plus) (*Moya et al., 2005*)

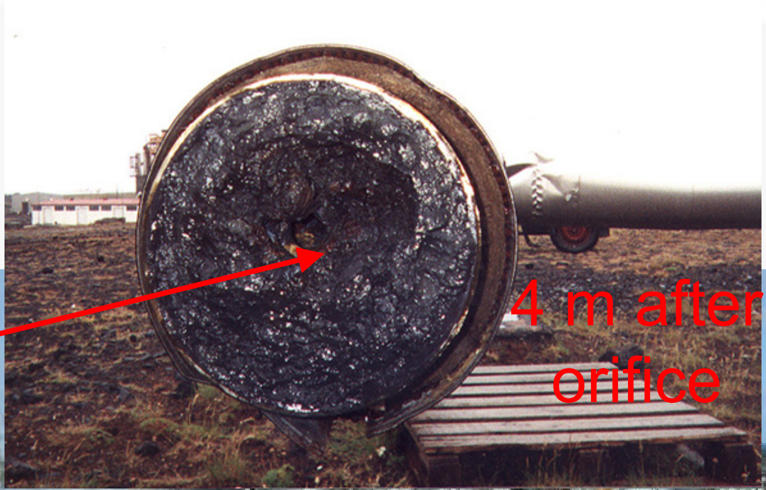
Scaling in surface equipment

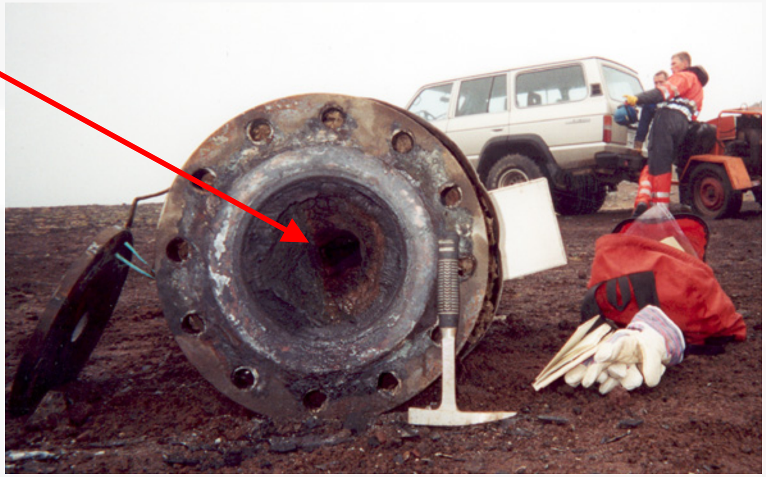
- Sulfide rich scales
  - Close to wellheads
- Silica rich scales
  - Further away from wellheads, common after separator stations

Sulfide rich scales

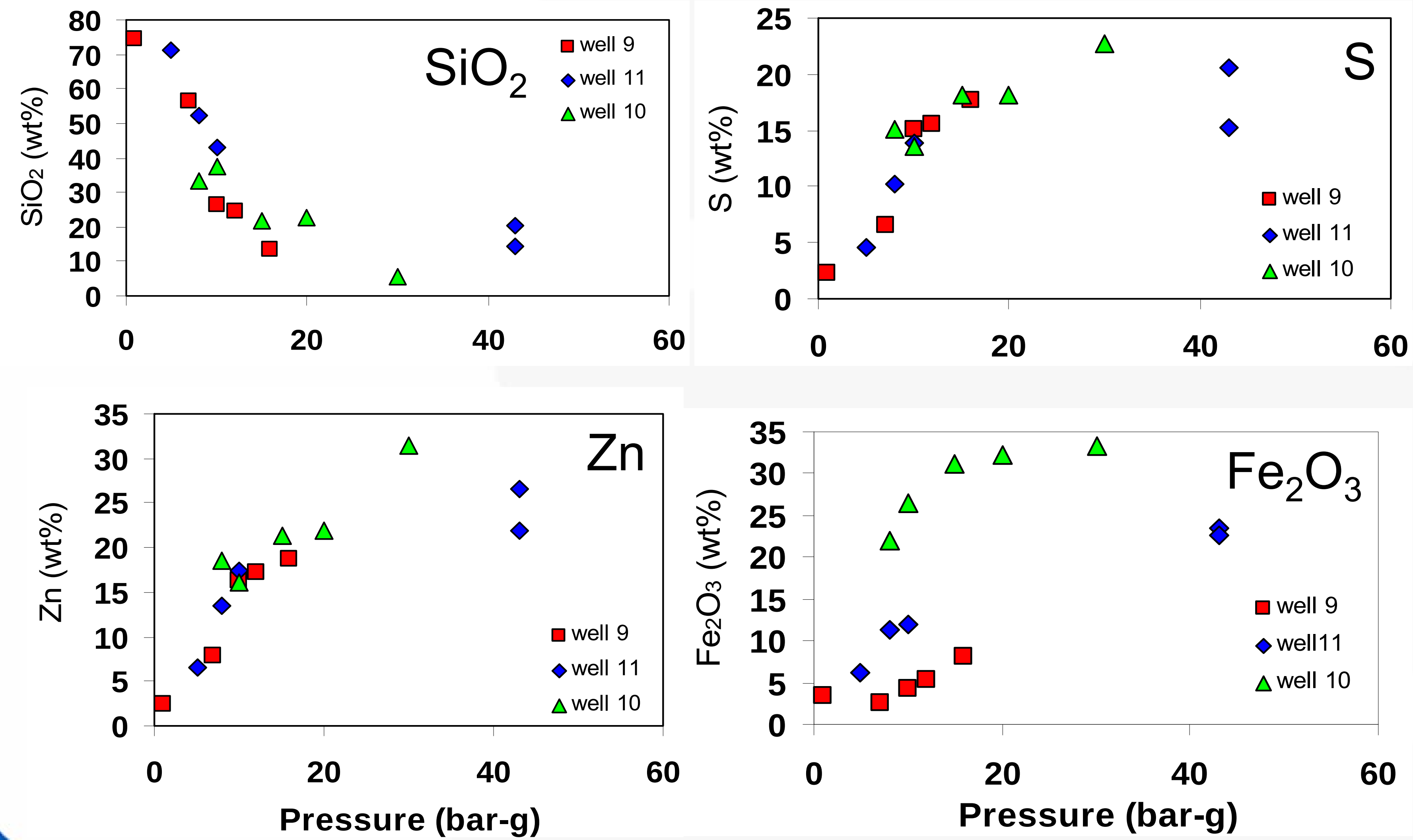
- Form where pressure drops (orifices)
- Same process as in downhole example (i.e. pH increaes due to boiling)
- Most abundant near wellheads, i.e. at high pressures
- Typical phases are iron-, zinc-, copper-, lead-sulfides, and an amorphous Fe-Si phase

Sulfide rich scales in pipeline from well 9 at Reykjanes, SW Iceland





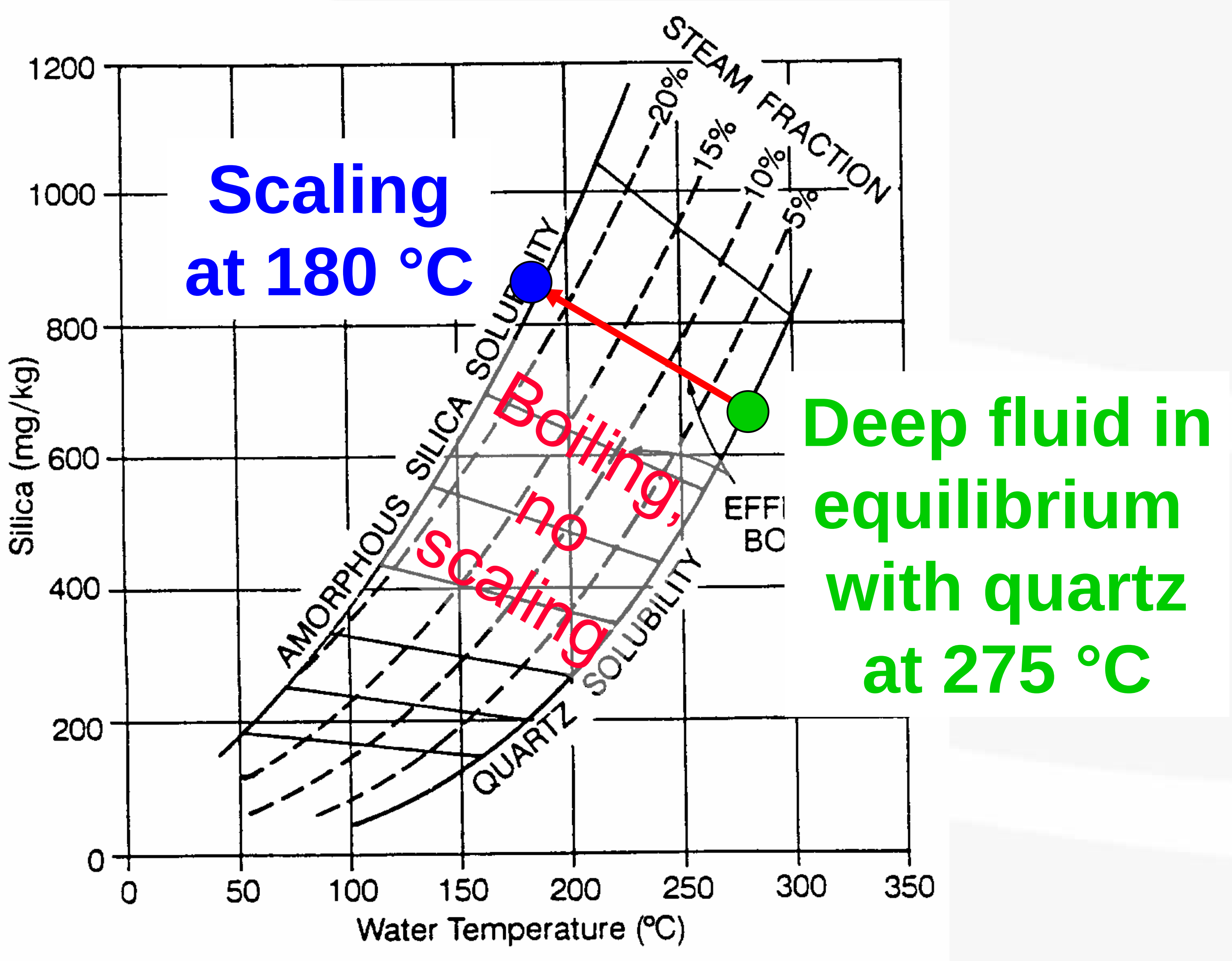
Reykjanes scale compositions as a function of pressure



Silica rich scales

- Amorphous silica – not quartz!
- Deep fluid saturated with respect to quartz
- Boiling increases concentration of dissolved SiO_2
- When the fluid reaches saturation with respect to amorphous silica scales form rapidly and in large quantities
- Problematic in injection wells and surface pipelines, particularly after separator staions

Silica solubility and scaling



Silica rich scales in a pipeline from a seaparator station at Reykjanes, SW Iceland

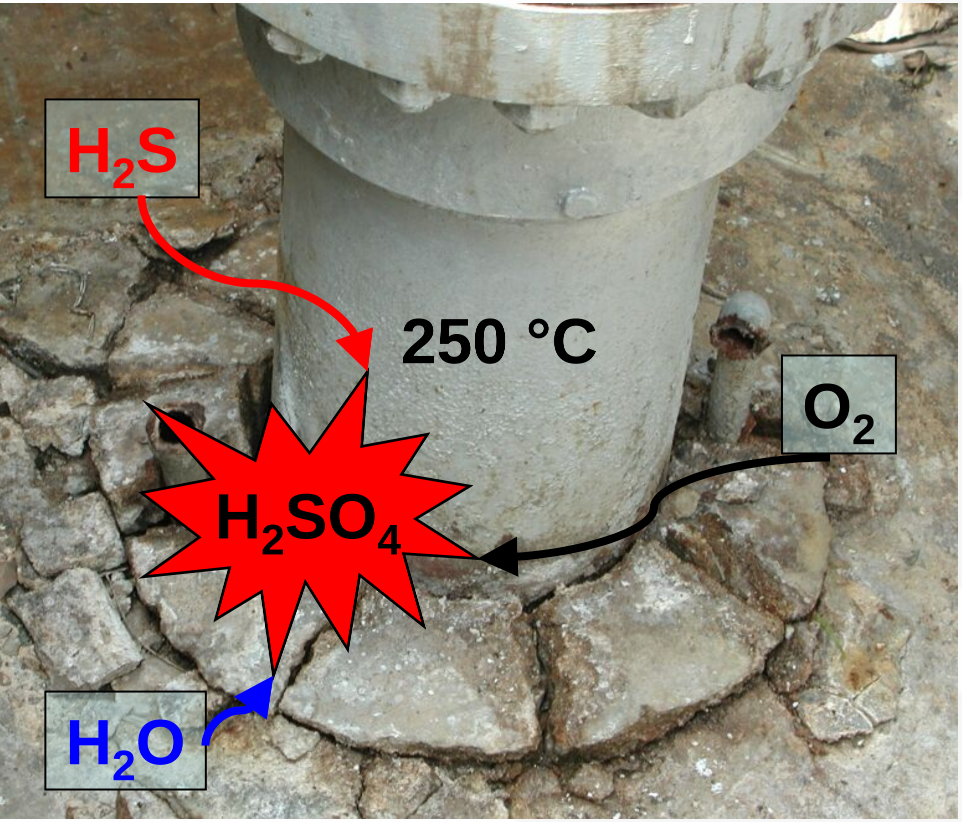
Silica rich scales: common solutions to the problem

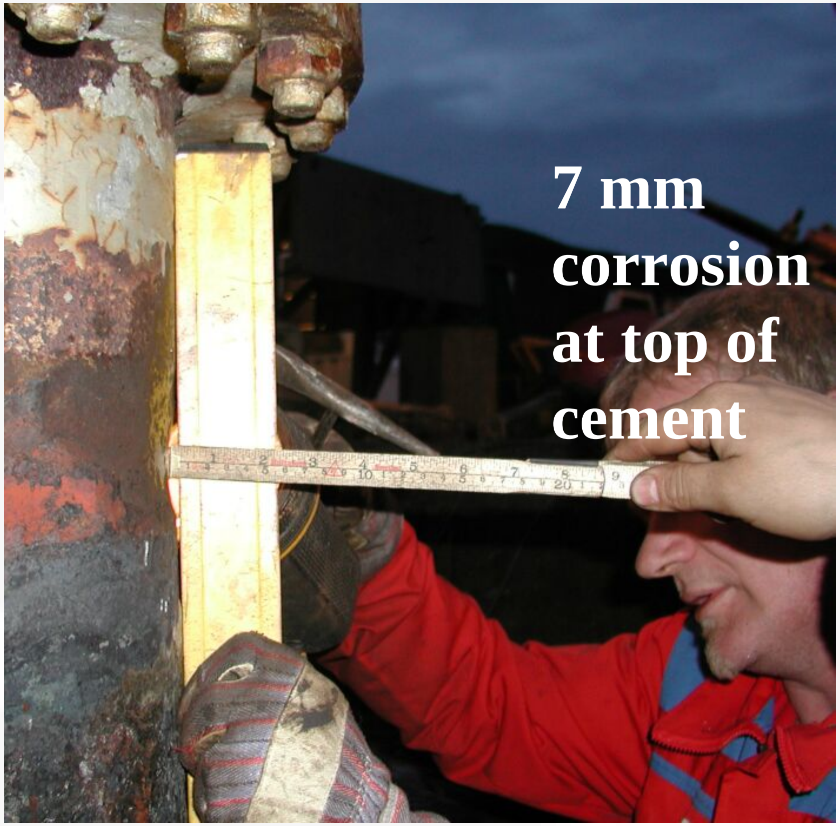
- Separating steam at high pressure
  - Wasteful, a lot of thermal energy wasted
- Diluting separated water with condensate
  - Can cause corrosion
- Acidification
  - Can cause corrosion
- Crystallize silica in suspension (Crystallizer-Reactor-Clarifies process)
  - Costly

Corrosion: common problems

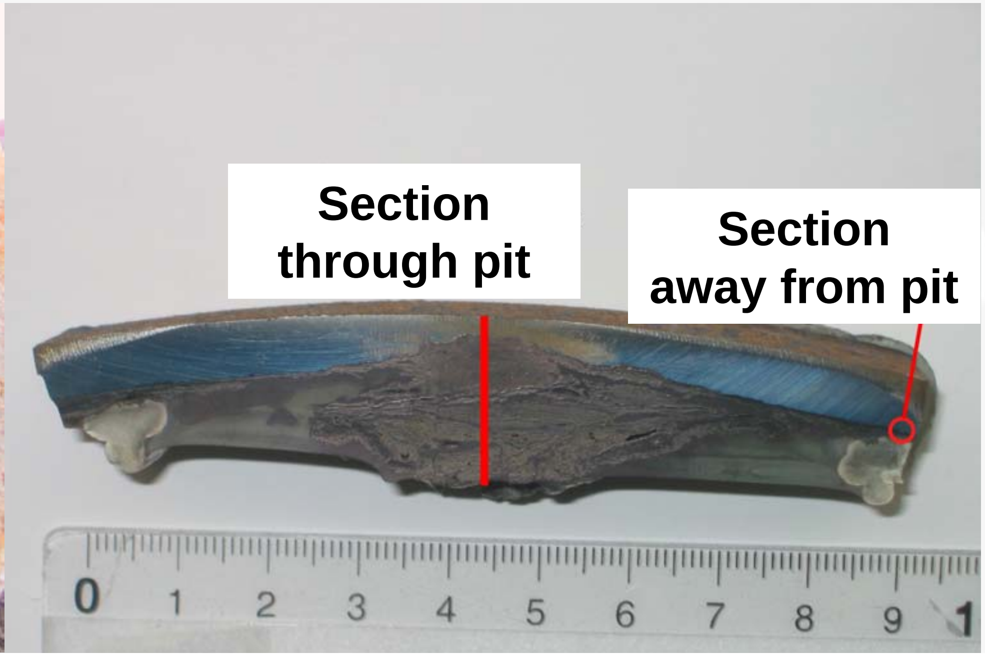
- In slotted liners and well casings
  - In hot systems where deep fluid is acidic and/or saline
  - H_2S can also cause sulfide stress cracking
- At well head: first meter below the cellar floor from outside
  - Water, oxygen and H_2S
- Superheated steam pipelines
  - First condensate is very acidic, may contain HCl
- Cooling towers and cold condensate pipelines
  - Condensate is acidic, free carbonic acid very aggressive to steel below 100 °C
- Heat exchangers
  - Stress corrosion cracking where O_2 and Cl^- are present at temperatures above 70 °C
- Electronic equipment in power plants
  - H_2S destroys copper wires in electronic devices

Corrosion by cellar floor: most common location

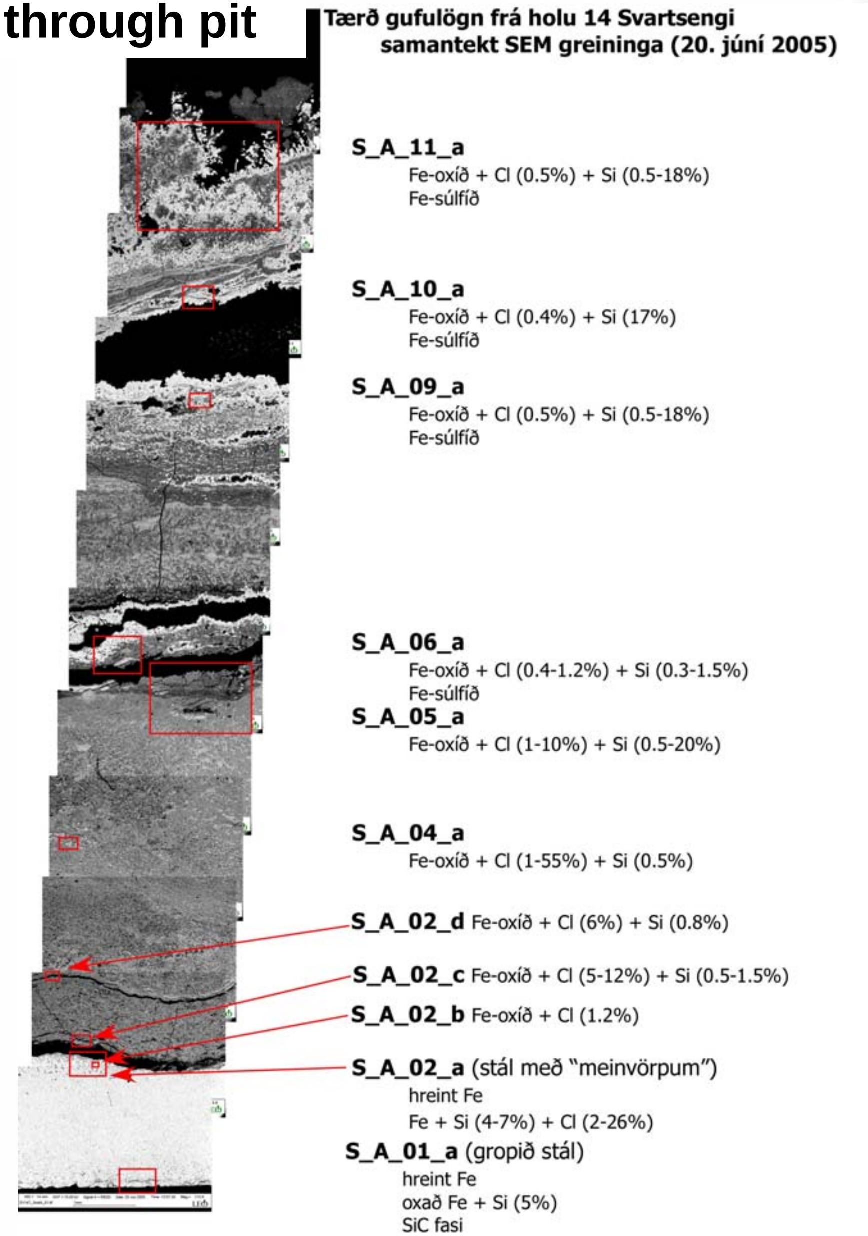




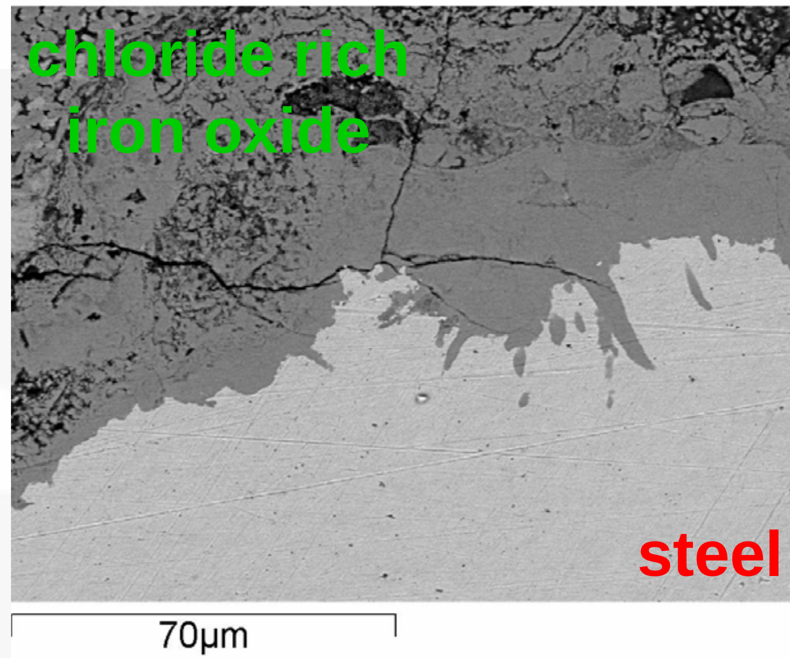
HCl corrosion in steam pipeline from Svartsengi, SW Iceland



Section through pit



Section away from pit



Solutions to most corrosion problems: Careful material selection

- Do not use high yield-strength steel for casing and liners (use K-55 or L-80)
- Cr-steel might be needed for the uppermost 100 m of casing
- Use mild steel for steam pipes
- Super heated steam pipes should be insulated and scrubbing might also effectively prevent corrosion in such pipes

Material selection continued

- Use titanium alloy in heat exchangers if geothermal solution contains high concentrations of Cl^-
- Use stainless steel, fiber glass, and polypropylene plastic for condensate pipelines
- Use high-temperature cement to fix casings
- H_2S must be scrubbed from the atmosphere in rooms containing electronic equipment and special solutions are required for electronic equipment outside of these rooms

If geothermal fluid is very acidic it can be neutralized by injection of caustic solution (e.g. NaOH) through a capillary pipe

NaOH storage tank at well site

Caustic solution pumps at well site, Miravalles Costa Rica

Conclusions

- Most of the unique problems that have to be dealt with at geothermal power plants are related to the chemistry of the fluid.
- Some of these have resulted in reduced production or a shut-down.
- There are proven methods to manage most of these problems but they will not be overcome completely. Sulfide scaling the most difficult and scaling of reinjection wells.
- The problems will change over time, due the effects of prolonged exploitation of the reservoir.
- Monitoring of the geothermal reservoir and fluid produced is therefore important.
- Effective maintenance procedures have been developed.
- Geothermal plants require the services of experts as well as highly qualified personnel in operation and maintenance.
- Geothermal plants can thus be operated–WITHOUT SURPRISES

P.S.

- Select geothermal areas with temperatures in the range 180-290°C.
- For the temperature range 180-240°C beware of calcite scaling, 240-290°C of silica scaling, >290°C of silicate and sulfide scaling.
- In process design “respect” the silica solubility curve.
- Avoid reservoirs with high gas or acidic steam.
- Use proven equipment and designs.
- Monitor the effects of production.