Simulating Salt Precipitation in Dry Gas Reservoirs Using ECLIPSE Thermal CO2STORE

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The present study considers the causes of precipitation of dissolved salts from the reservoir water and at the current modeling solutions of the phenomenon using existing commercial reservoir simulators. Consequently, we investigate the capabilities of ECLIPSE family of simulators in terms of showing the salt falling out of solution in the near wellbore region and across the reservoir as we deplete it. The work has been undertaken due to the fact that the wells' production coming from mature dry gas reservoirs is much affected by this salt precipitation, both in the wellbore and near wellbore region, and in order to know when to intervene the well for sweet water washing of these deposits. This is the first successful approach in using Schlumberger's ECLIPSE Thermal CO2STORE and Petrel, as a pre/post processor, in order to determine when salt falls out of solution.

Keywords: Reservoir simulation, ECLIPSE, mature gas reservoirs, salt precipitation.

The flow of dry gas through porous media vaporises water in order to fulfil thermodynamic requirements at a given pressure, temperature and salinity of the brine saturating the rock. The development of an increasing number of high-pressure, high temperature (HPHT) gas fields has arisen important issues concerning inorganic deposition in these systems given their frequently high salinity brines [1]. This phenomenon likewise occurs during the injection of dry gas into porous aquifers [2].

Sodium chloride is not strictly a scale. Most oilfield scales are formed by the mixing of incompatible waters. Salt, however, is a self-scaling phenomenon requiring only changes in physical conditions to precipitate. It is also, generally, a gas well problem, for reasons that become apparent when looking at the mechanism of salt deposition [3].

There are two mechanisms working to cause precipitation of salt; firstly, evaporation of fresh water from formation brine into the production gas which increases brine salinity, and secondly, changes in pressure and temperature which can reduce the solubility of the salt in the brine. Either or both can result in the brine becoming salt saturated so that salt precipitates out. Precipitated salt is generally nearly 100% NaCl [3].

Salt problems occur over a very limited range of producing conditions and are generally seen in mature, depleted gas fields, explaining perhaps the recent increasing interest in the issue amongst North Sea operators (UK and Netherlands). Salt solubility in water decreases both with reducing pressure and temperature [3].

Field observations of salt deposition in gas wells show that salt may accumulate:

-in the wellbore and perforation zone - it is common to observe deposition of salt in the wellbore and tubing which are then cleaned with periodic water wash operations. In order to have this phenomenon occurring, mineralised reservoir water will need to reach the wellbore. The source of this water can be: expansion of the water in the pores to a value above the critical water saturation allowing mineralised water to flow as the pressure in the reservoir decreases, compaction of the porous medium, or production of trace brine from anomalously high water saturation intervals. This water is being sprayed into the wellbore and, when flowing velocity of the produced stream will be lower than the critical value that can transport this water to the surface, it will segregate into the wellbore. The gas stream will contribute to the vaporization of pure water from the mixture. The brine from the wellbore gets oversaturated in NaCl until its critical precipitation concentration is reached. Sodium chloride solubility limit in water is 360 g/L. From this point further, the process will continue and solid salt will block the wellbore and the opened perforations [4, 5].

-in the near wellbore region and reservoir – the production of water vaporized in the gas phase is controlled by the local conditions around the wellbore. The pressure gradient applied to the formation creates a sharp increase of the molar water content in the hydrocarbon phase approaching the well; this leads to a drop in the pore water saturation around the wellbore. The extent of the dehydrated zone which is formed is the key in controlling the bottom hole content of vaporized water. Knowing exactly the water content of the gas leaving the perforations is fundamental. This is the starting point for understanding many phenomena occurring in the tubing, such as scaling, corrosion, etc. [6,7].

ECLIPSE is the industry reference reservoir simulator in which we are trying to model the above processes. An input file for it has 8 sections used to define the characteristics of the reservoir, produced fluids and wells' production and constraints. These 8 sections are:

-RUNSPEC-general characteristics of the simulation: grid dimensions, fluid phases present, start date of the simulation, system of units being used, etc.;

-GRID- the reservoir geometry and its properties: porosity, permeability, etc.;

-EDIT -section used to alter characteristics of the above introduced grid geometry and properties; this sections is mostly used during history matching runs;

-PROPS - fluid properties, rock dynamic flow properties: relative permeabilities, capillary pressures, etc;

-REGIONS - section used to divide the reservoir into compartments: layers, fault blocks, etc.

-SOLUTION - initial conditions of the reservoir, aquifer properties if any, etc.

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SUMMARY – section used to request output from the simulator, e.g. flow rates, pressures, ratios: WCUT, GOR, etc.

SCHEDULE – section used to introduce wells and their characteristics and advance the simulation time –here the simulation can be defined as a history match or a forecast, or both reunited under the same simulation case.

For production operations, a vital requirement for allowing prompt implementation of stimulation measures is the early detection of salt precipitation based on simple criteria [8]. As shown by experience, in practice, a consideration of the productivity index of gas wells is not sufficient for the detection of plugging by salt precipitates. The subsequent stimulation measures have frequently proved to be too late for restoring the original flow conditions [4]. That's why, in order to avoid such late interventions, it would be effective to know when to intervene from simulations. As we have seen that salt can precipitate both in the wellbore (perforations) and in the reservoir (near wellbore), simulation solutions for both scenarios should be supplied. Unfortunately, for the first category, at the moment, there is no commercial wellbore simulator which properly models the phenomena - ECLIPSE is a reservoir and not wellbore centric simulator.

For the second category, the phenomena happens in the reservoir. Implicitly, a reservoir simulator has been looked at [9]. As such, in the following analysis we assume that the water liquid phase is not moving: the pressure decreases as the gas approaches the well. The molar water content of the gaseous phase increases. Thus, water is transferred from the liquid phase to the gas phase leading to a drop in trapped water saturation around the wellbore and an increase of the salinity of the remaining connate water [10]. Zuluaga et al. have conducted experiments to evaluate the rate of water vaporization and the consequent permeability reduction caused by the flow of dry gas through porous media. Tests indicate that the rate of water vaporization increases with gas flowrate and temperature and decreases with salinity. The vaporization of water from the porous media can result in halite drop out and this might cause a reduction of the permeability. In consolidated cores, vaporisation could be catastrophic for permeability, a reduction of about 50 % was measured in this laboratory study for high salinity brine. After vaporization, the saturation left in the rock is very low. This suggests that vaporisation caused by dry gas flow is a mechanism that could vaporise large amounts of water causing serious impairment to reservoirs with high salinity brines [1].

In order to have ECLIPSE simulate the above phenomenon, modifications in the RUNSPEC, GRID, PROPS, SOLUTION and SUMMARY sections are needed. The most important refer to the fluid model and therefore the PROPS section. Thermal CO2STORE + SOLID options of ECLIPSE will have to be used. SOLID will allow the existence of the solid NaCl through precipitation and, also, permeability multipliers tables as functions of solid saturation. Thermal CO2STORE is used to allow hydrocarbon components in the reservoir fluid extending the list of the currently available CO_2, H_2O, NaCl, $CaCl_2$, and $CaCO_3$ by CO2STORE with CH_4, C_2H_6 etc.[11].

A rectangular theoretical model having 588 cells (7x7x12) is being used and presented in figure 1. The dimensions of one cell are 50 m x 50 m x 7.5 m. Constant static geological properties are being used, horizontal permeability of 200 mD, vertical permeability of 1mD, porosity of 0.2. The production well is placed in the middle of the grid. The initial volume of gas in place is 373 MMscm. The considered hydrocarbon gas is pure methane, CH_4.

The reservoir water in place molar fractions are 0.92 for H_2O and 0.08 for NaCl. The initial water saturation is constant throughout and has a value of 0.2. The resulted initial water density is 1151 kg/m^3.Well's initial plateau flowrate of 233,000.00 scm/d is requested to be maintained for meeting contractual requirements. The limit on the bottom hole flowing pressure is 5 bars. In order to closely investigate results and observe the salt deposition, the initial grid resolution needs to be refined locally.

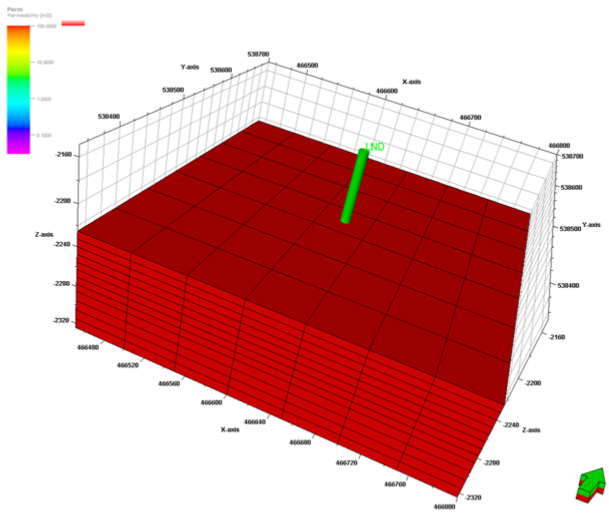

Fig. 1. 3D representation of the static model

Results and discussions

Before running and investigating the results of this simulation, salt is most likely to precipitate in the near-wellbore region. Therefore, our analysis should confirm this and it does as per the message received from the simulator, solid NaCl precipitates at a specific date within specific cells. This message is presented in figure 2. In order to make connections to the phenomena the well's behaviour is presented in figure 3. The difference between the

```
@--Message at 1415.50000  Days 15 Feb 2020
@ Solid precipitate in cell (9,9,44)
@--Message at 1415.50000  Days 15 Feb 2020
@ Solid precipitate in cell (9,9,45)
@--Message at 1415.50000  Days 15 Feb 2020
@ Solid precipitate in cell (9,9,46)
@--Message at 1415.50000  Days 15 Feb 2020
@ Solid precipitate in cell (9,9,47)
@--Message at 1415.50000  Days 15 Feb 2020
@ Solid precipitate in cell (9,9,48)
        Time   Step     GOR    WCT    OPR    WPR    GPR    FPRP   OIR    WIR    GIR    It
        Days   Days     SM3/   SM3/   SM3/   SM3/   SM3/   Bars   SM3/   SM3/   SM3/
                        SM3    SM3    Day    Day    Day           Day    Day    Day
----  ------- -------- ------ ------ ------ ------ ------ ------ ------ ------ ------ ---
HRep;  1415.5   14.50     0.0 1.0000    0.0 3.0453 2.3E05 22.015    0.0    0.0    0.0   2
@--Warning at 1415.50000  Days 15 Feb 2020
@ JALS Non-Linear Convergence problem
@       Residual too large by a factor of    1.8
@--Message at 1430.00000  Days  1 Mar 2020
@ Solid precipitate in cell (9,9,25)
@--Message at 1430.00000  Days  1 Mar 2020
@ Solid precipitate in cell (9,9,37)
@--Message at 1430.00000  Days  1 Mar 2020
@ Solid precipitate in cell (9,9,38)
@--Message at 1430.00000  Days  1 Mar 2020
@ Solid precipitate in cell (9,9,39)
@--Message at 1430.00000  Days  1 Mar 2020
@ Solid precipitate in cell (9,9,40)
```

Fig. 2. Run results -clear message from the simulator with salt precipitating in specific cells

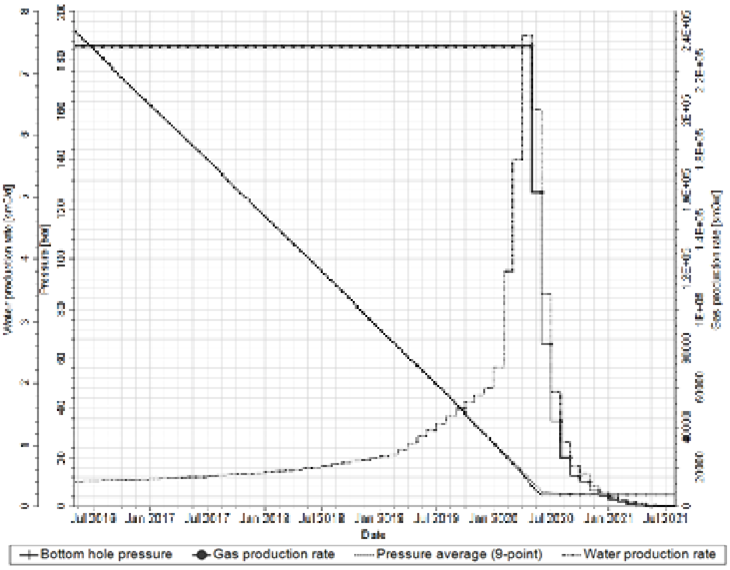

Fig. 3. Well's behaviour throughout simulation

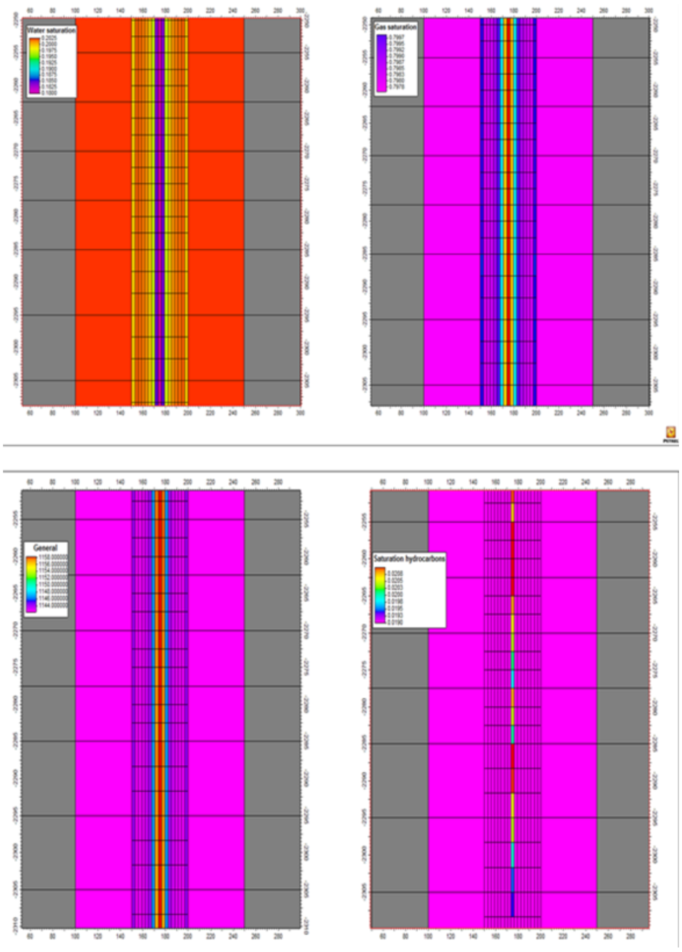

Fig. 5. Fluid (above) & Solid Saturations (below, Right) Profile and Water Density (below, Left)

reservoir pressure, Pressure average (9-point) and well bore pressure, Bottom hole pressure, is very small and this is due to the good permeability of the reservoir.

As we deplete the reservoir the produced water flowrate is increasing. In general, the lower the pressure, for constant temperature, the higher the vaporization rate is and more vapour water enters the production stream, behavior which is confirmed in figure 3 [12]. The measured salinity of this produced water at surface conditions (1 atm, 15 °C) is 0, with other words, this is sweet water. This means that the

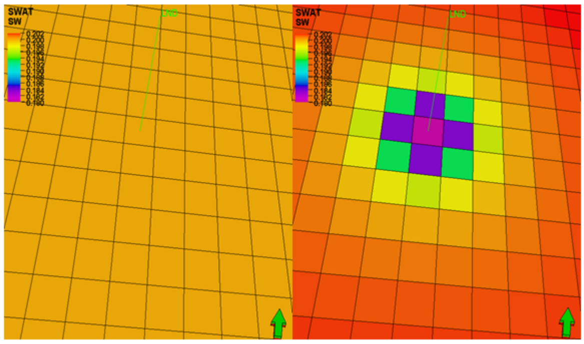

Fig.4. Water Saturation Profile at first (left) and last (right) time step - view from above

water remaining in place, in lower and lower quantity [13], as shown in figure 4, gets more and more staurated in NaCl, until saturation concentration is being reached and the first cristal of salt precipitates as shown by figure 2.

From this point further, the phenomenon continues. In the fine resolution region, throughout a 25 m radius around the well, if we look at a cross section of water saturation, water density, and solid saturation, the cells in which solid is precipitating (in fig. 5, right hanside have a different colour than the big majority), have a much lower saturation and, implicitly, a much larger density than its neighbours.

This concludes our experiment and confirms the fact that ECLIPSE succesfully simulates precipitation of solids in the near wellbore vecinity.

Conclusions

Considering that ECLIPSE is a reservoir centric simulator and not a wellbore centric simulator, the present work does not address the well plugging with salt due to the flow of reservoir water which gets dried out into the wellbore. However, this study looks at how can we use ECLIPSE to model salt precipitation into the near wellbore region and the reservoir;

If expert judgement based on detailed knowledge of the system under investigation and core floods experiments are at hand, formation damage and productivity issues can be quantified with the help of ECLIPSE simulator;

In addition to the above formation damage and productivity issues, water production along with gas presents an economical and safety threat in terms of hydrate plug formation in the tubing and surface facilities. This workflow accounts for water production prediction which will help in choosing and designing hydrate inhibition techniques/facilities.

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