DTI SHARP (Sustainable Hydrocarbon Additional Recovery Programme) IOR Views

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Long Term Temperature Changes from Injection of Sea Water

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The temperatures observed at a newly drilled Magnus injector were substantially below the initial reservoir temperature, even though a nearby injector has been shut-in for nine months. There was surprise that the cooling had lasted for so long. Jeff Masters (**jeff.masters@ecltechnology.com**) of ECL Technology Ltd has investigated the persistence of the reservoir cooling that occurs after long periods of sea water injection. This work was undertaken as part of DTI's OG-MRP (Maximising Recovery Programme). More detailed results can be in be found in **"Persistence of Temperature Effects from Sea Water Injection"**, presented at IEA Collaborative Project on EOR, Annual Workshop and Symposium, Stavanger, September 2004

Introduction

This study was prompted by observations on a newly drilled Magnus injector for which the measured temperatures were substantially below the initial reservoir temperature [1]. This well was drilled close to a previous injector that had been shut in for the previous nine months. Water injection in that well would have acted to cool the reservoir, but there was some surprise that the cooling would have lasted so long. This short study investigated the long term temperature changes from sea water injection.

A literature search was performed, followed by some simple calculations concerning temperature changes using thermal properties from the literature. The literature contained little information regarding the duration of reservoir cooling. However, data relating to thermal properties of reservoir rocks has been measured, but mostly in the context of thermal recovery processes such as steam flooding.

Analytic Solution

An analytic solution exists which corresponds to an idealised representation of a cooled reservoir where the reservoir region has been cooled to temperature T_c, but the cap and base rocks remains at the original temperature T_o. If the reservoir has thickness $2h$ with centre at depth z=0, then the temperature profile assuming conduction only, from time t=0, is given by:

$$\frac{T(z,t)-T_c}{T_o-T_c}=\frac{1}{2}\left\{erfc\left(\frac{h-z}{2\sqrt{\kappa t}}\right)+erfc\left(\frac{h+z}{2\sqrt{\kappa t}}\right)\right\}$$

In particular the temperature at the centre of the formation (z=0) is given by:

$$\frac{T(z,t)-T_c}{T_o-T_c}=erfc\left(\frac{h}{2\sqrt{\kappa t}}\right)$$

The following data have been assumed in evaluating this solution.

Quantity	**Value**
Thermal diffusitivity	9.6×10^{-7} m^2/s
Rock density	2080 kg/m^3
Heat capacity	1000 J/kg/K
Thermal conductivity	2 J/m/K/s.

The solution has been plotted for various formation thicknesses from 3 to 150 metres (10 to 500 feet) in Figure 1. There is a dramatic increase in the time required for the centre of the reservoir to warm as the thickness is increased. The centre of the 3 metre reservoir (h = 1.5 metres) reaches 85% of the temperature difference after approximately 1 year, whereas a period of 100 years is required for a reservoir of 30 metres. Essentially the time increases with the square of the reservoir thickness.

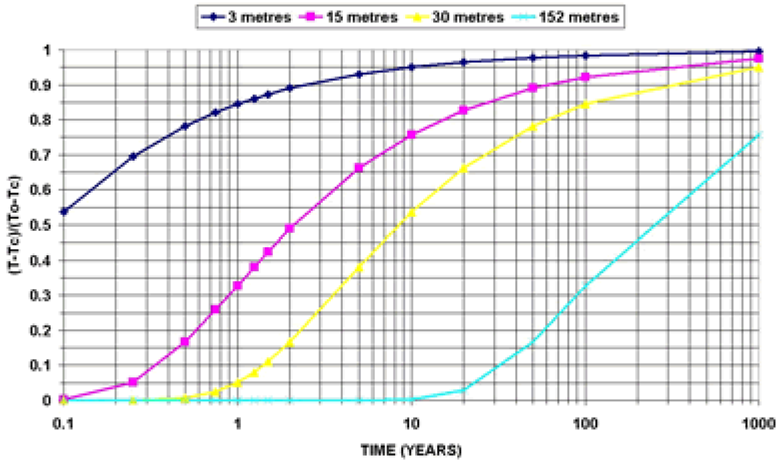

Figure 1: Variation of Temperature at the Centre of Reservoirs of Varying Thickness

Simulation

The temperature effect was also investigated using a simulator. A single well model was constructed using radial geometry. The original reservoir temperature was set to 96°C (205°F). Approximately one pore volume of cold water, at temperature 24°C (75°F), was injected at the centre of the model over a period of 10 years. This was followed by a lengthy shut-in, to determine how quickly the reservoir temperature rises. Thermal boundaries were modelled using both grid blocks out to a thickness of 1000 feet and analytic models applied to the faces of the reservoir. The impact of reservoir thickness was examined by modelling several thicknesses of 3, 7.5, 30, and 150 metres (10, 25, 100 and 500 feet).

Following cessation of water injection, the reservoir is slow to warm. Even for thin reservoirs (~3 metres) significant cooling may persist in the near well region for at least two years. The size of the cooled region and the time required for it to warm increases with reservoir thickness. For thicker reservoirs, measurable temperature drops may still persist after 100 years. Figure 2 shows the temperature profile through the model containing a 30 metre reservoir interval between 1830 to 1860 metres.

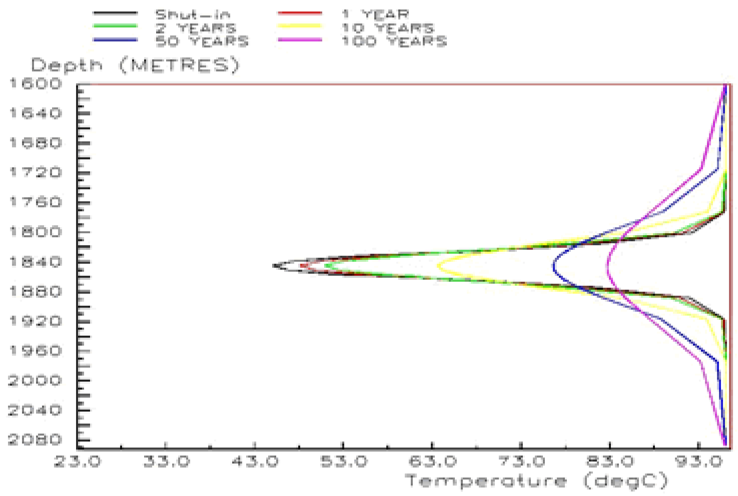

Figure 2: Temperature Profile in Simulation Model

Conclusions

The degree of reservoir cooling primarily depends on how much cold water flows through the rock. The injected water is heated by the formation resulting in a temperature front which travels much more slowly than the water front. Reservoir heterogeneity, which causes water channelling, may result in deeper penetration of the temperature front. However, heat flow through the formation cools adjacent regions of the reservoir largely bypassed by water. Where either the water swept or unswept regions are thin, this results in a fairly homogeneous temperature profile. The depth of heat penetration can be estimated enabling the assessment of the impact of heterogeneity on the temperature distribution.

The heat flow through the base and cap rocks is limited by the thermal conductivity of the rock. The reheating of the reservoir is retarded by the regions of the base and cap rocks which are cooled during injection. Consequently, the cooled reservoir region grows with reservoir thickness for a given water throughput (in hydrocarbon pore volumes). The time required to warm the reservoir is also increased.

The convection of cold water is more effective at cooling the reservoir than conduction as can be seen by the fact that, for all cases run, the temperature front advances approximately seven times further into the reservoir than it penetrates into the base or cap rocks.

This study shows that the persistent nature of reservoir cooling caused by the injection of cold water should not be a surprise. Such effects could be expected for a reservoir where an interval of 10 metres or more has been cooled by injected water.

Reference

- *"Saturation Monitoring Behind the Magnus Flood Front"*, Graham Davis, BP, AFES/PESGB Extending Field Life Conference, May 2003.

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