Predicting SAGD Flow Performance from Geostatistical Models

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The application of Steam Assisted Gravity Drainage (SAGD) is important because of the vast reserves accessible with this production mechanism. Some common SAGD production performances include the oil production rate and the cumulative steam oil ratio which are economically important. These variables depend on geological heterogeneity, which is the distribution of petrophysical properties (porosity, permeability, volume of shale) within the distribution of facies. In addition to petrophysical properties, the SAGD performance depends on the thickness and structure of the reservoir. The reservoir thickness is high in the middle of the reservoir channel and is low on the edges of the channel. SAGD production performance also depends on engineering decisions (location and orientation of SAGD pads, number of well pairs, steam injection pressure and temperature, etc). Predicting SAGD flow performance requires running flow simulator. In this paper some flow simulation results for three different SAGD pads (with the same geological properties, boundary conditions and reservoir fluid properties) are used to predict the SAGD flow performance for other SAGD pads (with the same geological properties, boundary conditions and reservoir fluid properties) which flow simulation is not run for them. The linear approximation is used for prediction. This fast method might be used instead of running flow simulator and spending lots of computational time for a large reservoir having lots of grids to have an idea about the SAGD performances. The uncertainty due to the geostatistical models can be quantified in the predictions. The whole idea is to correlate a dynamic property (e.g. cumulative oil production) of the reservoir with a static property (connected pore volume) of the reservoir. We do not recommend this prediction instead of flow simulation but it is useful just for having an idea of the behavior of the well pairs. Of course there is uncertainty in this prediction but it can be assessed using the uncertainty in geostatistical models. The method of prediction can also be improved.

Introduction

The SAGD process was invented by Dr. Roger Butler in 1978 for in-situ heavy oil recovery. Steam is injected in an upper injection well to lower the viscosity of surrounding oil allowing it to drain along a growing cone-shaped steam chamber into a lower production well via gravity. The most powerful instrument available for forecasting reservoir performance is flow simulation, but flow simulation requires significant computational time.

The SAGD production performance parameters considered in this work are cumulative oil production, instantaneous oil rate, cumulative steam-oil-ratio, and cumulative steam injection. Several reservoir parameters and their associated uncertainties impact on SAGD performance. Some of these parameters are structural uncertainty (uncertainty in top and bottom of reservoir), uncertainty in distribution of facies, lithology (distribution of impermeable shale) and petrophysical properties. Figure 1 shows the impact of impermeable shale layer above the injector and producer. Presence of impermeable shale layer decreases the oil production rate and increases steam oil ratio.

Simulation runs from STARS

Three different SAGD pads (A, B and C) are flow simulated. They belong to the same reservoir channel with the same boundary conditions and the same reservoir fluid properties. Pad A contains 3 SAGD well pairs, pad B has 6 well pairs and pad C has 5 well pairs. There are 14 well pairs totally. Prior to flow simulation the geostatistical simulation is performed and P50 case is chosen from 50 geostatistically simulated realizations. First top and bottom of the reservoir are simulated then effective porosity is simulated within the top and bottom of the reservoir. Due to the lack of facies data for this particular real SAGD case, facies are ignored in the modeling. Ranking of the realizations was based on connected pore volume. Figure 2 shows the ranking criteria check for pad A. It shows the connected pore volume versus the net pore volume. Figure 3 shows the water cut and oil production rate as a function of time for these 14 well pairs. Simulation is run for 10 years.

Predicting SAGD Performance Parameters from Static Reservoir Property

In Figure 3, curves showing high oil production rate belong to the portion of reservoir channel which has more potential to recover bitumen (basically they are in the middle of the channel) and the well pairs which are on the edge of channel have low oil production rate because of the thin thickness of reservoir on the edge. This shows that the oil production rate which is a dynamic parameter is related to some static reservoir parameter (e.g. reservoir thickness, pore volume, connected pore volume, original bitumen in place, etc). In some cases the reservoir thickness might be high but the oil production rate is low, this might be due to other reservoir features, for example there might be an impermeable shale layer above the injector which does not allow the steam chamber to grow. Therefore each of the curves in Figure 3 relates to a reservoir with a specific reservoir index (e.g. connected pore volume). At each specific time step there are 14 values for oil production rate and other calculated dynamic parameters. These 14 values at each time step is related to 14 reservoir indices (reservoir index is constant over time). So at each time step a crossplot can be constructed and correlation coefficient between the instantaneous dynamic reservoir property and the static reservoir property can be calculated. The plot of this correlation coefficient versus time can be made. Figure 4 shows the correlation coefficient between *oil production rate - connected pore volume* and *water cut – connected pore volume*. The dynamic properties are also correlated with *net pore* volume, Figure 5, 6 and 7 show the correlation coefficient between these three dynamic properties *cumulative oil production*, *cumulative steam injection, cumulative steam oil ratio* and *net pore volume*. This plot shows high correlation coefficient after a certain amount of time (about 500 days). It means that a linear approximation can be used to predict the SAGD performance. Any dynamic property can be predicted using a static reservoir parameter if the correlation coefficient is high (i.e. greater than 0.7 or less than -0.7). The linear approximation for oil production rate and water cut is given below:

$$q_o(CPV,t) = A_1(t)\cdot CPV + B_1(t)$$
$$f_w(CPV,t) = A_2(t)\cdot CPV + B_2(t)$$

Where

- CPV is the P50 value of the connected pore volume
- $q_o(CPV,t)$ is the oil production rate for a reservoir with connected pore volume of *CPV* at time *t*
- $f_w(CPV,t)$ is the water for a reservoir with connected pore volume of *CPV* at time *t*
- $A_1(t)$ and $A_2(t)$ are the slopes for the linear approximation of oil rate and water cut versus *CPV* at time *t*
- $B_1(t)$ and $B_2(t)$ are the y-intercepts for the linear approximation of oil rate and water cut versus *CPV* at time *t*

Figures 8 and 9 show the slopes ($A_1(t)$ and $A_2(t)$) and *y*-intercept ($B_1(t)$ and $B_2(t)$) of the linear approximation of the dynamic properties of the reservoir. Using the above linear approximation and Figures 8 and 9, the SAGD flow performance can be predicted for other well pairs in the same reservoir channel. This prediction is done for a SAGD pad which contains 6 well pairs. The STARS results are available for these 6 well pairs. These 6 well pairs are not used for obtaining the approximation parameters ($A_1(t)$, $A_2(t)$, $B_1(t)$ and $B_2(t)$). The only thing that we need is the connected pore volume for these well pairs. Figures 10, 11 and 12 show the prediction results and the STARS results for this SAGD pad. The plots for errors are also shown. The errors are in fraction between -1 and 1. We do know there is uncertainty in the SAGD flow performance. The SATRS results are for P50 case. There might be a proxy model which we can obtain a case which can approximate P50 case better. Both SATRS results and the prediction results have uncertainty. There is uncertainty in connected pore volume. Assessing the prediction uncertainty using the linear approximation in SAGD flow results can be obtained more easily and faster than assessing the uncertainty in SAGD flow results using STARS. We can give a range of values for connected pore volume to the linear approximation and get a range of flow results curves for different *p* values.

Conclusion and Future Work

This paper shows that predicting SAGD flow performance without running flow simulation is possible. Although there are some errors in the predictions with respect to flow simulation results but the way of getting the predictions is smart, easy and can be improved. The prediction uses the correlation between the dynamic property and the static property of the reservoir. This method is applicable for the SAGD pads with the same geological properties, boundary conditions and reservoir fluid characteristics. The correlation coefficient plots show high correlation after a certain amount of time. The linear approximation can be improved by other regression analysis techniques. The uncertainty in the predictions can be assessed by using the uncertainty in the geostatistical models and the uncertainty in the static property of the reservoir (i.e. connected pore volume). The geostatistical models which are used in this case study were generated without using facies data. Considering and simulating facies data will change the SAGD performance results. Ignoring of the facies data was due to the lack of data.

References:

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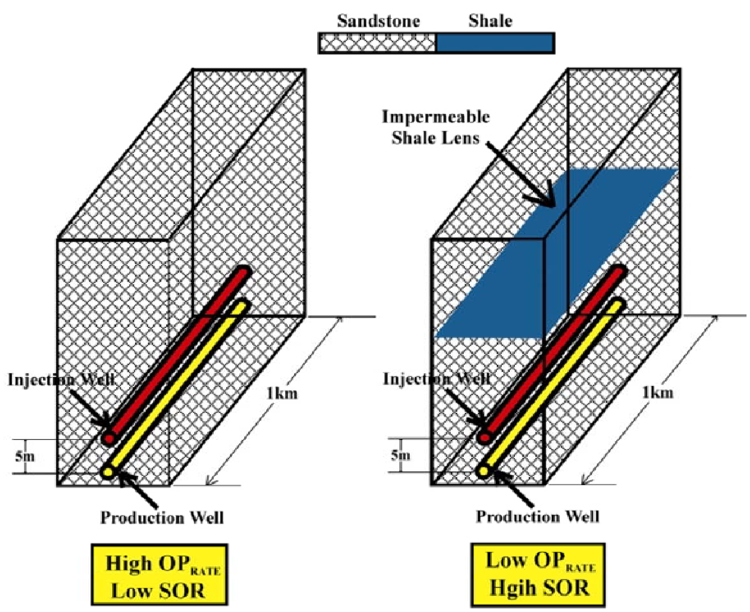

Figure 1 An impermeable shale layer affects SAGD flow performance, It decreases the oil production rate and increases steam oil ratio (Reference: McLennan et al, 2005)

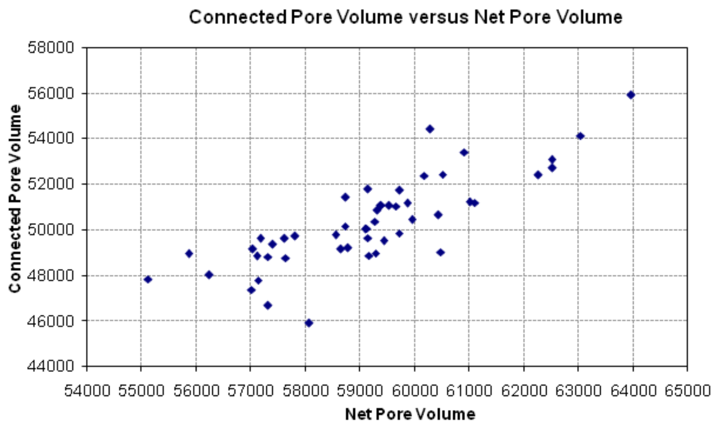

Figure 2 Connected pore volume versus net pore volume for SAGD pad A, connected pore volume is used for the ranking criteria to get the P10, P50 and P90 geostatistical reservoir models

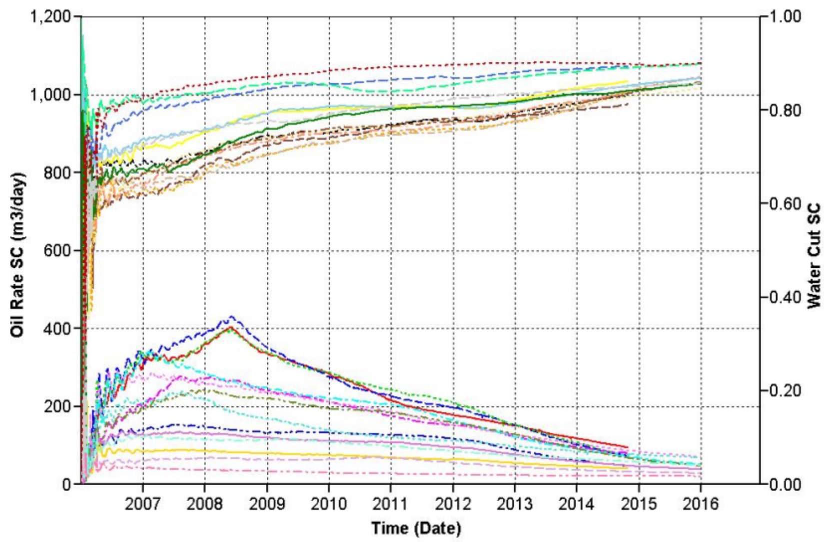

Figure 3 Oil production rate (curves at the bottom) and water cut (curves at the top) for SAGD pads A, B and C which contains 14 separate well pairs

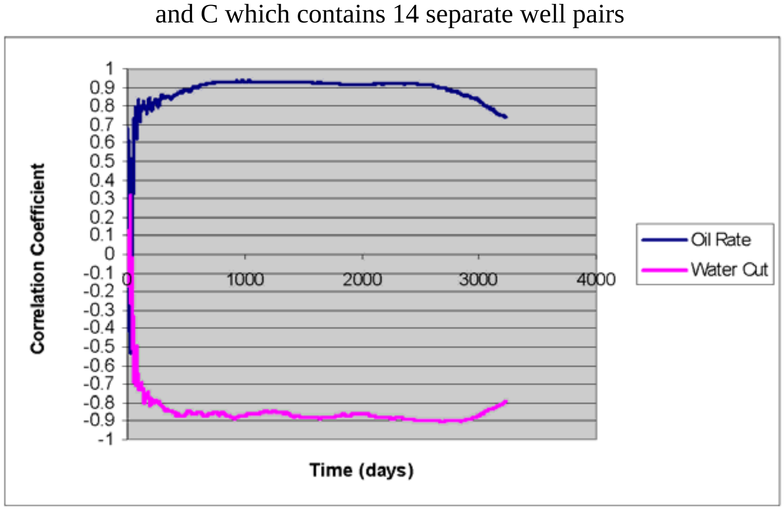

Figure 4 Plot of the correlation coefficient between dynamic properties (oil production rate and water cut) and static reservoir property (connected pore volume) as a function of time, oil production rate has positive correlation and water cut has negative correlation with connected pore volume

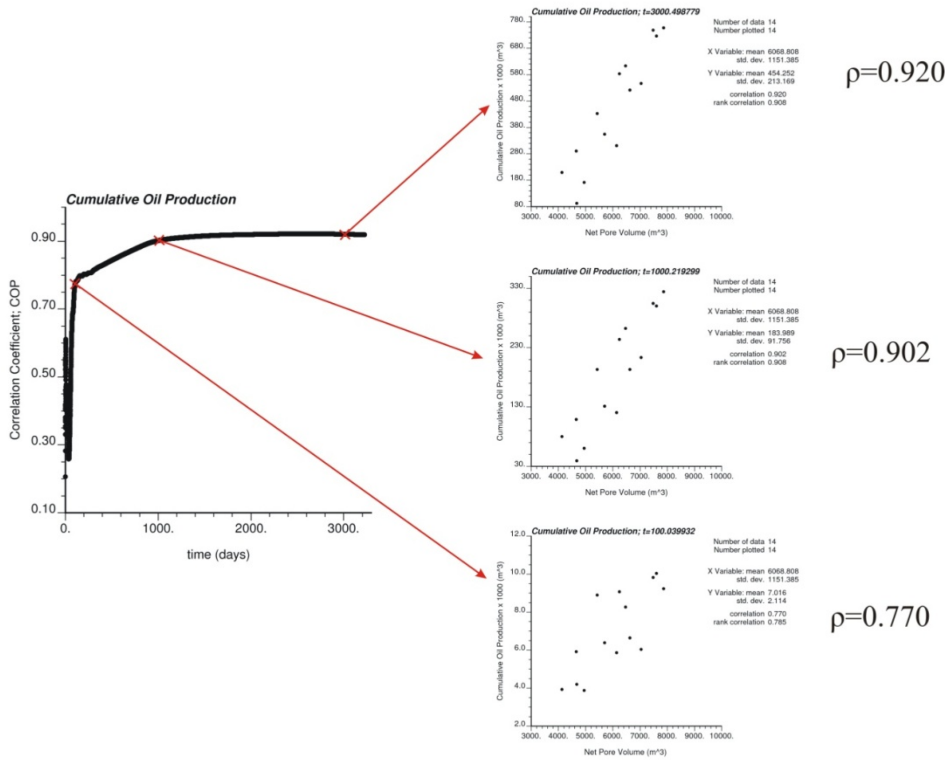

Figure 5 Correlation Coefficient for cross plot of cumulative oil production versus P50 net pore volume from geostatistical models

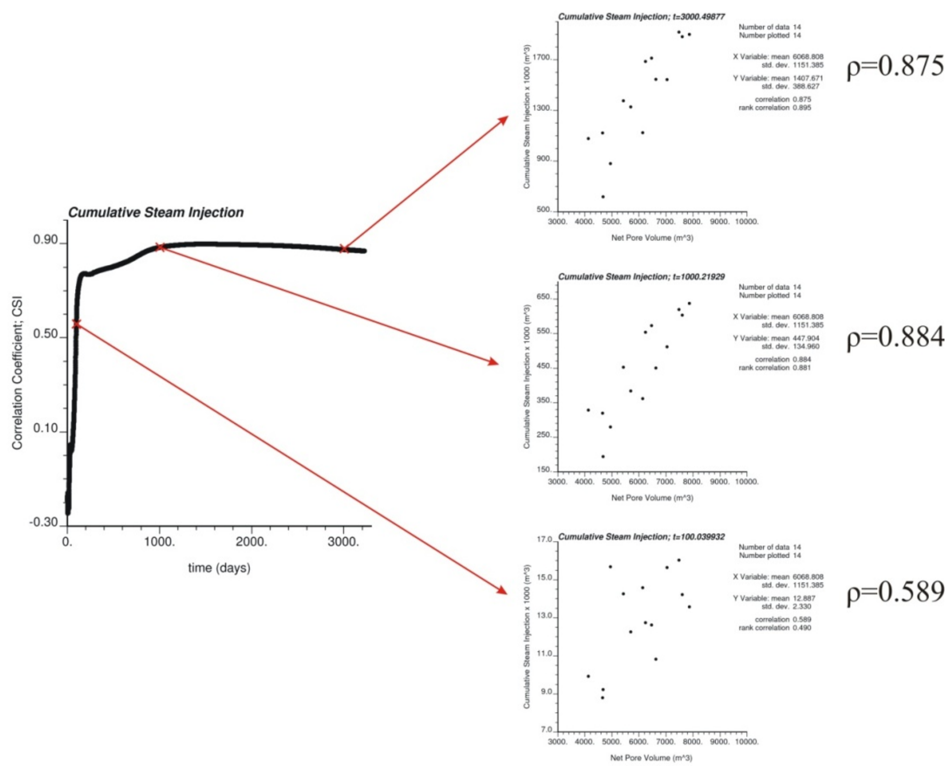

Figure 6 Correlation Coefficient for cross plot of cumulative steam injection versus P50 net pore volume from geostatistical models

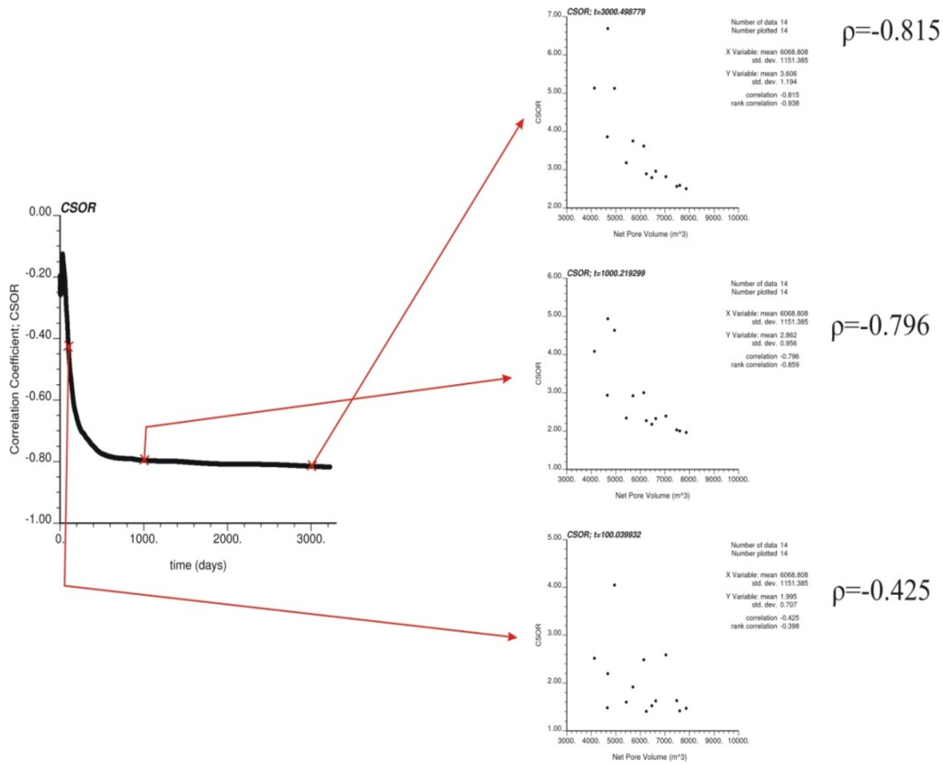

Figure 7 Correlation Coefficient for cross plot of cumulative steam oil ratio versus P50 net pore volume from geostatistical models

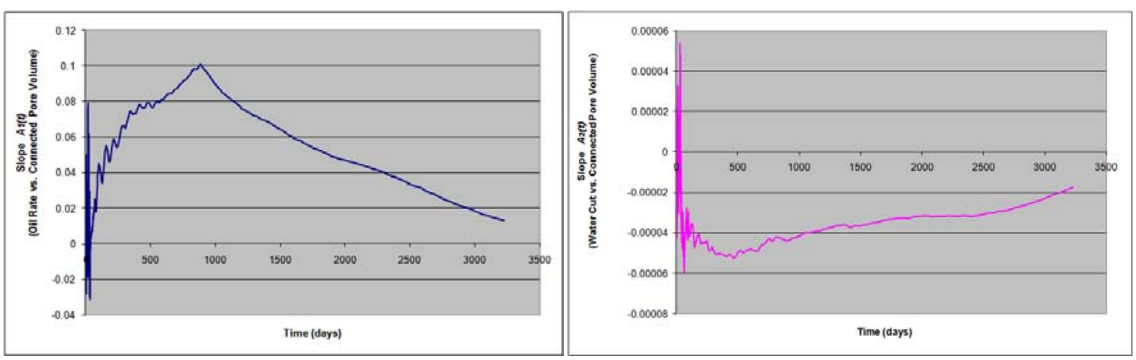

Figure 8 Slopes for the linear approximation of oil production rate, $A_1(t)$, and water cut, $A_2(t)$, versus time

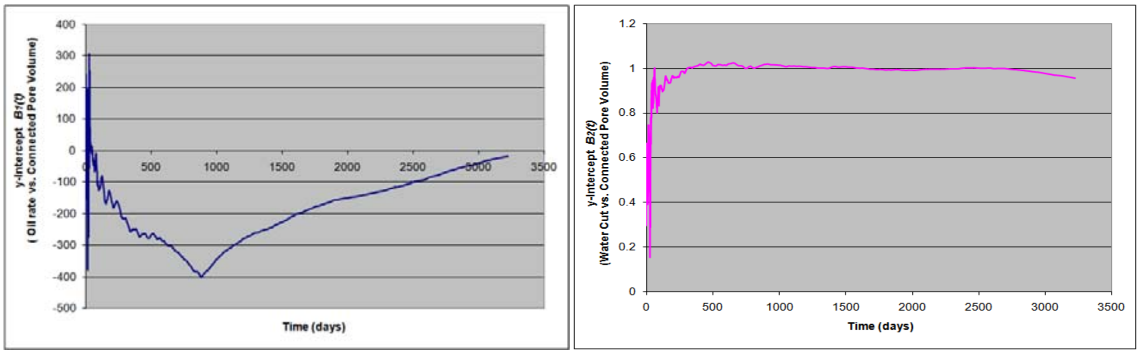

Figure 9 Y-intercepts for the linear approximation of oil production rate, $B_1(t)$, and water cut, $B_2(t)$, versus time

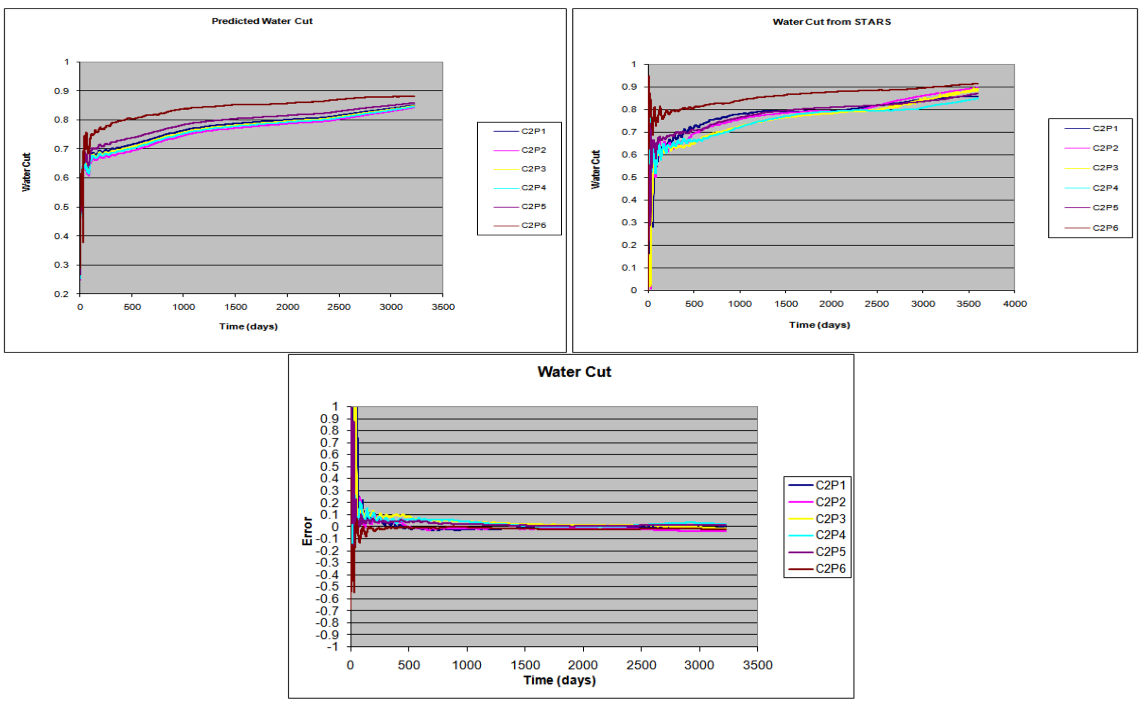

Figure 10 Predicted water cut using correlation (top left) for a SAGD pad, the flow simulated water cut using STARS (top right) for the same SAGD pad and the associated error (at the bottom), error is in fraction and it is between 1 and -1

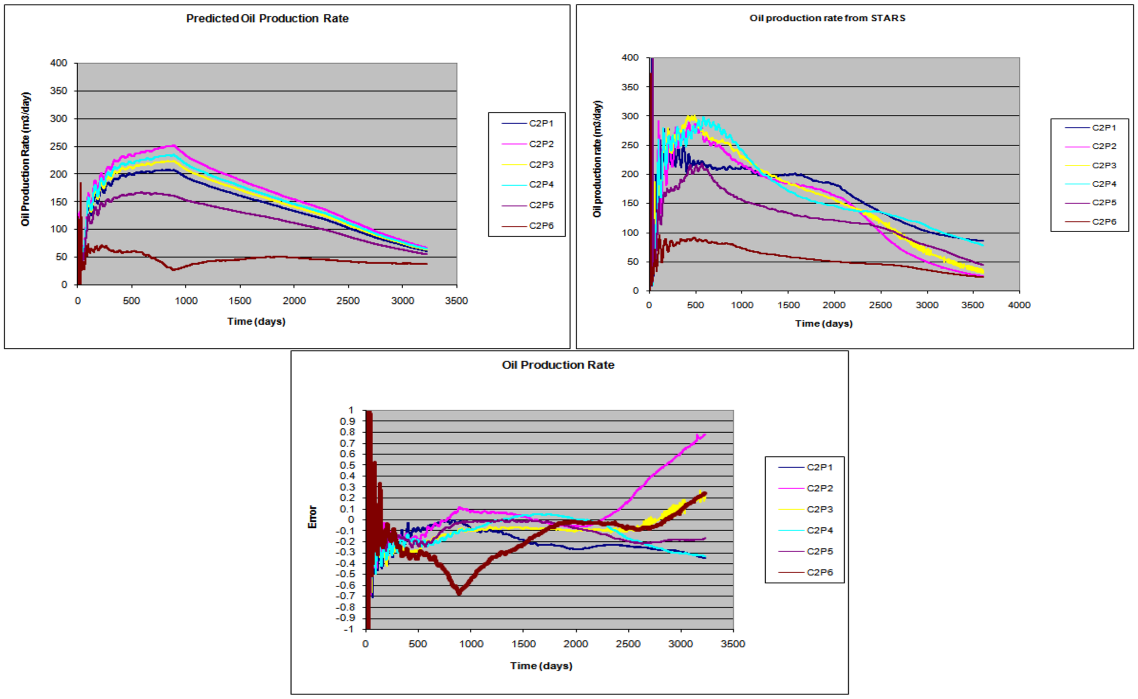

Figure 11 Predicted oil production rate using correlation (top left) for a SAGD pad, the flow simulated water cut using STARS (top right) for the same SAGD pad and the associated error (at the bottom), error is in fraction and it is between 1 and -1

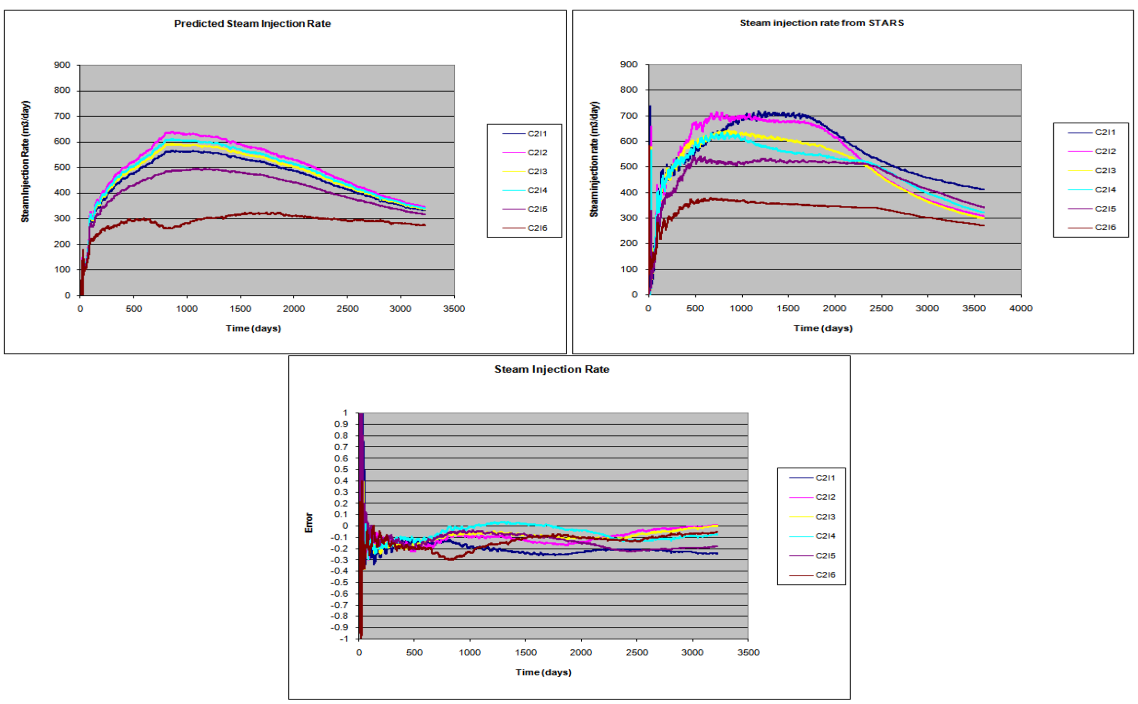

Figure 12 Predicted steam injection rate using correlation (top left) for a SAGD pad, the flow simulated water cut using STARS (top right) for the same SAGD pad and the associated error (at the bottom), error is in fraction and it is between 1 and -1