Ranking Realizations for SAGD Performance Predictions

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Geostatistical techniques are being increasingly used to generate reservoir models and quantify uncertainty in reservoir properties. This is achieved through the construction of multiple realizations constrained by all available data. A large number of realizations are required to capture the extreme low and high cases. Not all realizations can be used in flow simulation. However, randomly selecting realizations will result in inaccurate representation of the uncertainty. This paper presents a methodology for ranking the constructed realizations to reduce the number that must be processed in flow simulation. it is particularly suited to steam-assisted gravity drainage (SAGD) production. The ranking measure is highly correlated to performance parameters such as cumulative steam oil ratio (CSOR) and cumulative oil production rate (COP_{rate}). A large number of flow simulations were undertaken to illustrate that ranking measure works. Results show that ranking with connected hydrocarbon volume (CHV) can be correlated to SAGD performance parameters.

Introduction

Ranking is a step that is required before flow simulation. It is a useful geostatistical tool that is being widely used for reservoir analysis where significant variations are present in the reservoir properties. Efficient reservoir performance prediction requires an efficient ranking methodology to provide an accurate estimation of the reservoir properties and quantify the uncertainty associated with those properties. For predicting the recovery of hydrocarbon, understanding the geostatistical models is very important and has been given a great deal of attention. It is well known that uncertainty exists in oil and gas reservoirs. This uncertainty must be quantified for improved reservoir management.

SAGD is an in-situ heavy oil recovery process. Two parallel horizontal wells with vertical spacing of about 5m are drilled in the formation. The upper well is a steam injection well where steam heats the formation to increase the temperature and reduce the viscosity of the oil. The lower well is the production well where the heated oil can be drained and then pumped to the surface. A gravity driving force is introduced by injecting a steam in to the upper well. During the steam injection steam will rise and form a steam chamber, this process depends on the efficient connection of the steam chamber to the surrounding reservoir. Viscosity is an important issue in heavy oil production and lowering it is part of the SAGD process. The success of a SAGD project depends on controlling some parameters such as steam injection rate to minimize SOR and maximize the COP_{rate}.

Numerical reservoir models of porosity, permeability, fluid saturation and facies that are required for flow simulation are generated using geostatistical techniques. Cumulative steam oil ratio and cumulative oil produced are perhaps the most important performance measurements that we are trying to predict.

Generating Reference Realizations

Testing different ranking measures requires some true or reference results to assess the performance of the ranking measures. A number of different reference realizations are constructed to act as the reference values for developing ranking techniques. Several geostatistical models are used to generate the data. 100 realizations of porosity, permeability and fluid saturation were generated and considered as the reservoir properties along with reservoir lithofacies. Sandstone and Mud are considered as the two facies present in this example.

Performance Parameters

For the case of a SAGD drainage volume, the best ranking measure is correlated to important production performance parameters. The ranking can be achieved through the calibration of CHV with CSOR and COP. The multiple realizations of reservoir properties and facies that are generated by the geostatistical models imported to the flow simulator. The reservoir grids used in the flow simulator for SAGD are 100x1x100 in I, J and K directions respectively. Grid size was 1 m in I, K and 100m in J direction. The spacing is 5 m between the injector and the producer. The production well location is selected 3m from the bottom of the reservoir where the uncertainty below this will not be considered. However, in some realizations the well location has been chosen according to the property distribution, that is, in some realizations there is shale layer located above or at 3m from the bottom of the reservoir. The simulation time was for 10 years including 3 months of preheating of the reservoir.

Ranking Methodology

The ranking methodology is geostatistical tool used to calculate the connected hydrocarbon volume within a single SAGD drainage volume. It is based on calculating the connected cells within local window. Connected hydrocarbon volume (CHV) program is developed to calculate the local connectivity using geoobjects within the window and performed based on the following equation:

$$CHV = \frac{1}{L}\sum_{l=1}^{L}\sum_{j=1}^{N} i(u_j) * \phi_j * (1 - Sw_j) \tag{1}$$

The local connectivity is a relatively new ranking measure. However, it is considered as straightforward method compared with global connectivity measure. The indicator of connectivity is the net cells that connected to the producer. A net cell is considered as connected cell when $i(u_j) = 1$ whether or not directly connected above or below the same row of the cells. These net cells are part of the net facies and should be greater than the property cutoff. The cutoff is value of reservoir property at which below this value the cell considered as non net. For example if the value of the permeability cutoff is 150mD then any value below this will not be counted in the calculation and will be considered as non connected net cell. In this study the cutoff for the porosity, permeability and water saturation are 0.05, 100mD and 0.75 respectively. The window size is an important function and must be chosen carefully. The window size is considered along the well axis as shown in Figure 1.

The SAGD producer well is represented by the dot point from where the connectivity calculation will take place (see figure 1). The gray color is the non-net cells, the green is the net cells but not connected and the red color is the net cells considered as connected bitumen cells. If the well trajectory is used, which shows the well location from where the calculation will start, then line of sight is utilized to calculate the hydrocarbon volume from the connected cells along the axis of the producer. All net cells that are directly connected to the producer and are calculated by the line of sight will be added to the net cells calculated within the window size as shown in Figure 1.

If the well trajectory is not considered, the calculations will be performed in all X and Y grids. This could give inaccurate results. In that case calculations will search for the thickest connected interval and consider them as net cells. It is better to use fixed well trajectory if the well location is known. To evaluate sensitivity of results to the widow sizes, it is varied in the range of 20-50 m. The methodology was implemented and results were ranked to check the highest and lowest cases. Table 2 summarizes the first 15 ranked realization for different window sizes.

Modification to the Ranking Method

Heterogeneity always exists in any reservoir. This heterogeneity is also implies to the reservoir properties which are non-uniform or irregular in their distribution. For example the actual reservoir permeability varies in non-uniform distribution due to the heterogeneity of the reservoir. W. T. Cardwell et al stated that actual reservoirs have complicated shapes and non-uniform permeabilities and porosities.

The effective permeability is an important aspect in reservoir characterization and considered as the most significant reservoir properties that effecting fluid flow through the formation. There were many studies carried out for the effective permeability in the reservoir and investigated its affect in the fluid flow through a porous medium. W. T. Cardwell et al conducted their work by calculating the average permeability using two weighted average calculations, including average harmonic and average arithmetic. Clayton V. Deutsch has studied experimentally two methods to calculate the block effective permeability in both sandstone and shale. The two methods are including power-average and percolation models. Typically a geometric average ($\omega = 0$) is used for vertical permeability and arithmetic average ($\omega = 1$) is used for horizontal permeability where ω is the average power between -1 and +1.

The correlation between the ranking methodology and the SAGD performance parameters are need more improvement. Some of the realizations behave as unusually good where some as bad, it was also not easy to pickup P10, P50 and P90.

One observation from the results indicates that the permeability, especially around the well bore, playing big role in the flow of fluid in these realizations. To overcome this issue and improve the correlation it is better first to perform the calculation by considering the average effective permeability weighted in each layer for each realization and establish a dimensionless scaling factor (wt) then multiply this factor by the connected bitumen volume resulted from the ranking method.

The possible fluid flow directions that can be performed to calculate average weighted permeability are including horizontal, vertical and radial "around the well" flows. In the arithmetic averages, the calculation will take place along the X direction weighted by distance from the producer and according to the following equation:

$$K_{(arithmetic)} = \frac{\sum k_i}{N} \tag{2}$$

The harmonic averages calculation will be along the Z direction weighted by the distance to the producer and according to the following equation:

$$K_{(harmonic)} = \frac{N}{\frac{1}{k_i} + \ldots\ldots\ \frac{1}{k_n}} \tag{3}$$

Where: K is the average calculated permeability in both harmonic and arithmetic, Ki is the individual permeability for each grid in each layer. N is the number of the grids. The idea here is to sum all the calculated arithmetic average in the X direction with calculated harmonic average in Z direction to calculate the effective average permeability in all the directions according to the following:

$$\frac{1}{K_{eff}} = \sum_{layers} wt_l * \frac{1}{k_l} \tag{4}$$

After calculating the weighted average effective permeability, a dimensionless weighted factor will be established. The weighted factor considering one value for the net permeability as median value and calculate the factor according to the following equation:

$$F_{(K)} = 1 - e^{\left(\frac{-3K}{K_{net}}\right)} \tag{5}$$

The final modified connected hydrocarbon volume (CHVmodified) will be calculated based on the following equation:

$$CHV_{\mathrm{mod}ified} = F_{(K)} * CHV_{calculated} \tag{6}$$

The geostatistical ranking algorithm (the code built for ranking) wass modified to include the average permeability calculation.

Results and Discussion

A ranking methodology is required to reduce the number of the realizations that need to be processed in the flow simulator. In this study the data were first generated in Gaussian unit. A back transformation was performed to transfer the data from Gaussian unit to the original unit. Geological maps resulted from merging the petrophysical properties with geological facies are shown in obtained. The merged realization was first imported to CMG (STARS) to produce the performance parameters. Results from flow simulation were plotted. Histogram of the performance parameters were plotted from the results of CMG runs in order to check the upper and lower quantiles of the data. Figure 2 shows the oil per unit area before starting drainage from the reservoir. Figure 3 shows the same oil per unit area but after drained from the reservoir, this figure will be compared with Figure 8 to check how both methods are compatible together. Figure 5 shows the OOIP, CSOR and COP with the number of realizations respectively. It is clear that high correlation has been observed between OOIP and CHV where both CMG and CHV are calculating the OOIP correctly. The maximum, minimum and average values at which the CSOR becomes stable are identified. These are favorable values as in SAGD the attempt is to minimize this parameter. There is high correlation between CSOR and COP which is prove that those two parameters are dependent to each other in SAGD.

The CHV measure was implemented to calculate the connectivity of the bitumen volume within the local window. The calculations was conducted at different window sizes for single SAGD drainage volume, and then calibrated to reservoir performance parameters. Calculation accounts only for the connected net cells to the producer well but higher than the properties cut off condition. The results of the calculations are evaluated and plotted for CSOR, COP and OOIP parameters with CHV for different window sizes. Figure 9 shows maps of how the CHV was calculated at different window sizes. . Figure 10a, b and c show plots of CHV with OOIP, CSOR and COP at window size of 50m.

The results obtained from the modification of the ranking method must be convinced enough to ensure that this method can be used to rank the realizations. Figures 11 and 12 are plots of COP and CSOR with modified MCHV respectively. Big improvement by the modification has been observed. Most of the data located at low CSOR and high CHV, only a few data have high CSOR and low CHV.

Conclusion and Future Work

Ranking using the criteria removes the need for a large number of simulations. The Results from the ranking are important for reservoir characterization, managements and production performance predictions. The correlation of CSOR and COP with CHV calculated at the beginning were not high, this makes a modification to the ranking method is required. After the modification the correlation was improved and easy to pick few realizations for further analysis in the simulator. This methodology can be applied to different reservoirs by modifying the calculation procedure.

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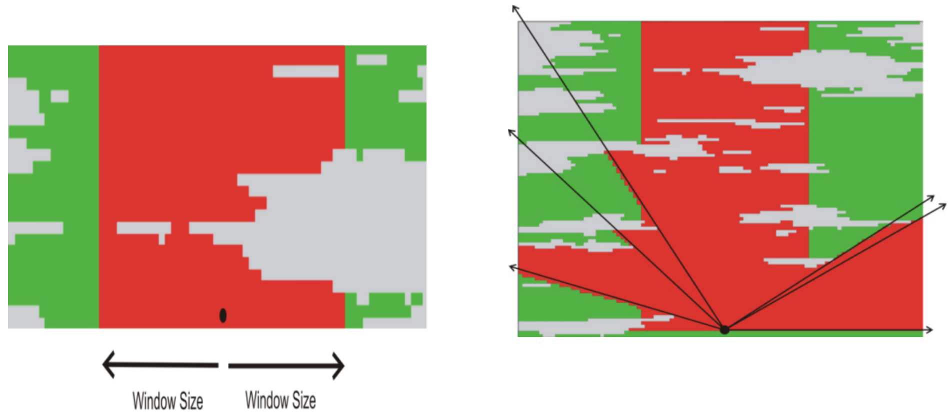

Figure 1: example of window size and directions of line of sight

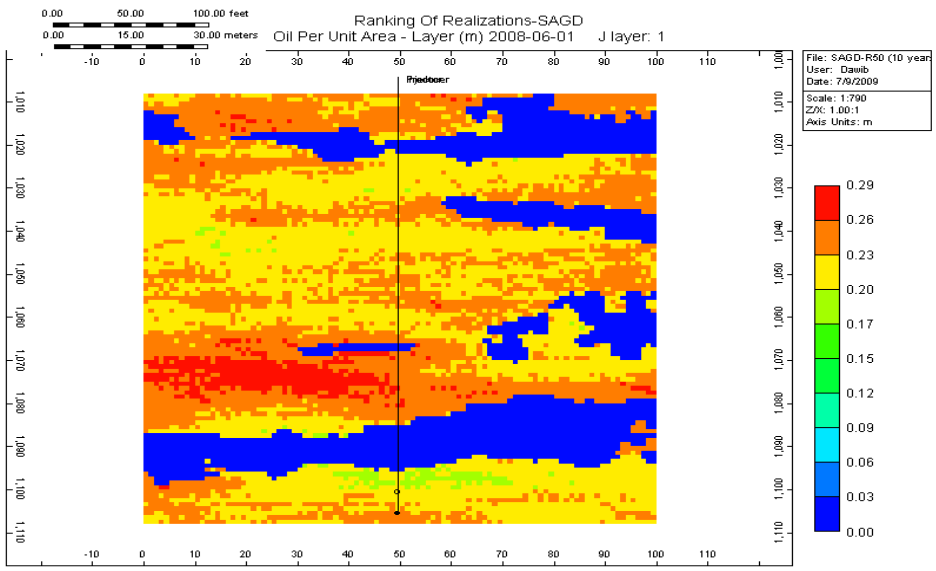

Figure 3: Plot shows the oil per unit area before drainage (R-50)

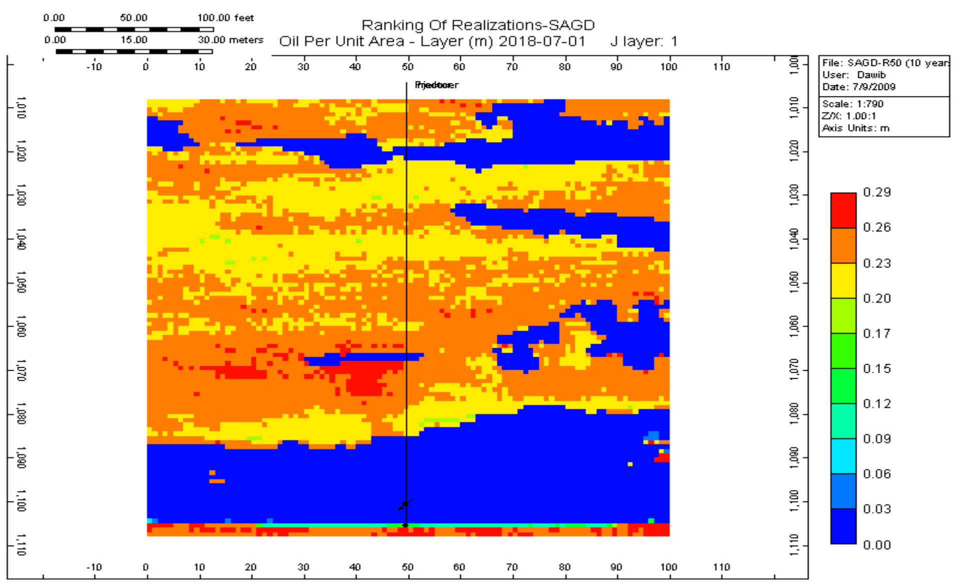

Figure 4: Plot shows the oil per unit area after 10 years of drainage (R-50)

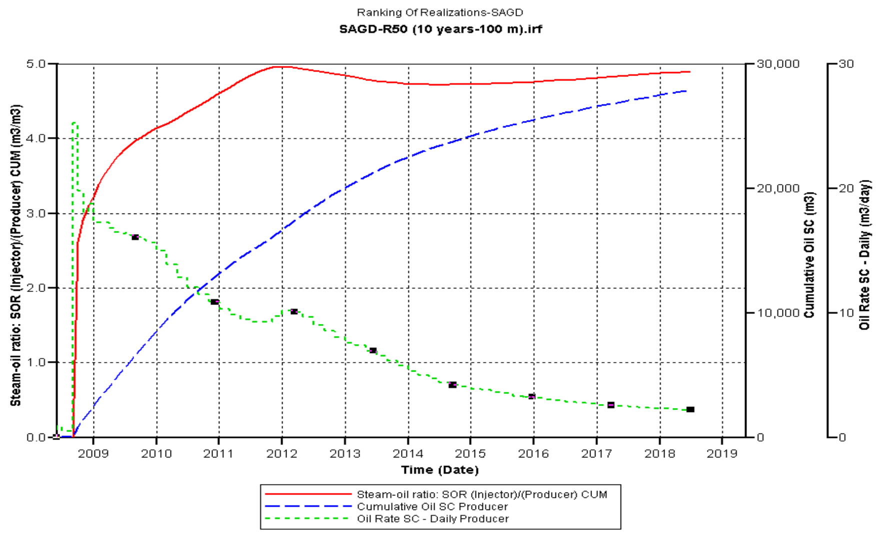

Figure 5: Plot of CSOR, COP and Daily OP for R-50

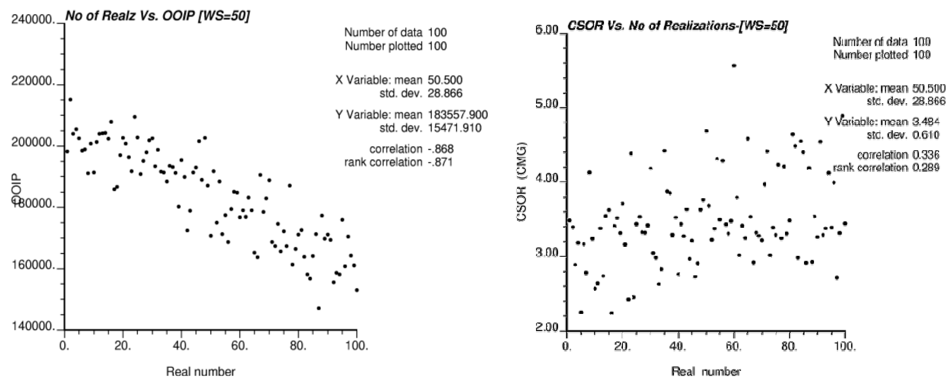

Figure 6: Plot of OOIP Vs. number of realizations and CSOR (CMG results)

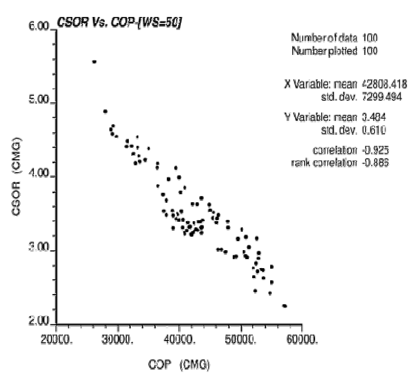

Figure 7: Plot shows correlation between CSOR and COP (CMG results)

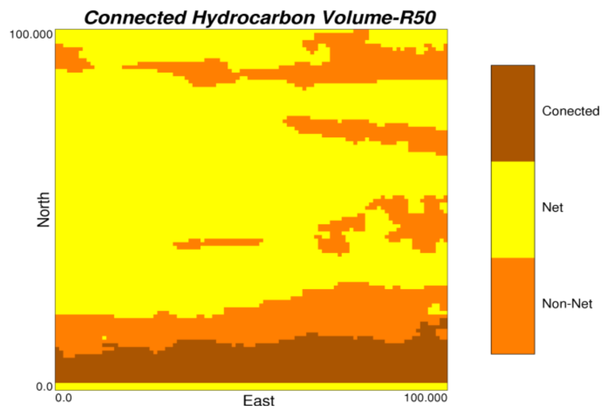

Figure 8: Map for Calculated CHV (R-50)

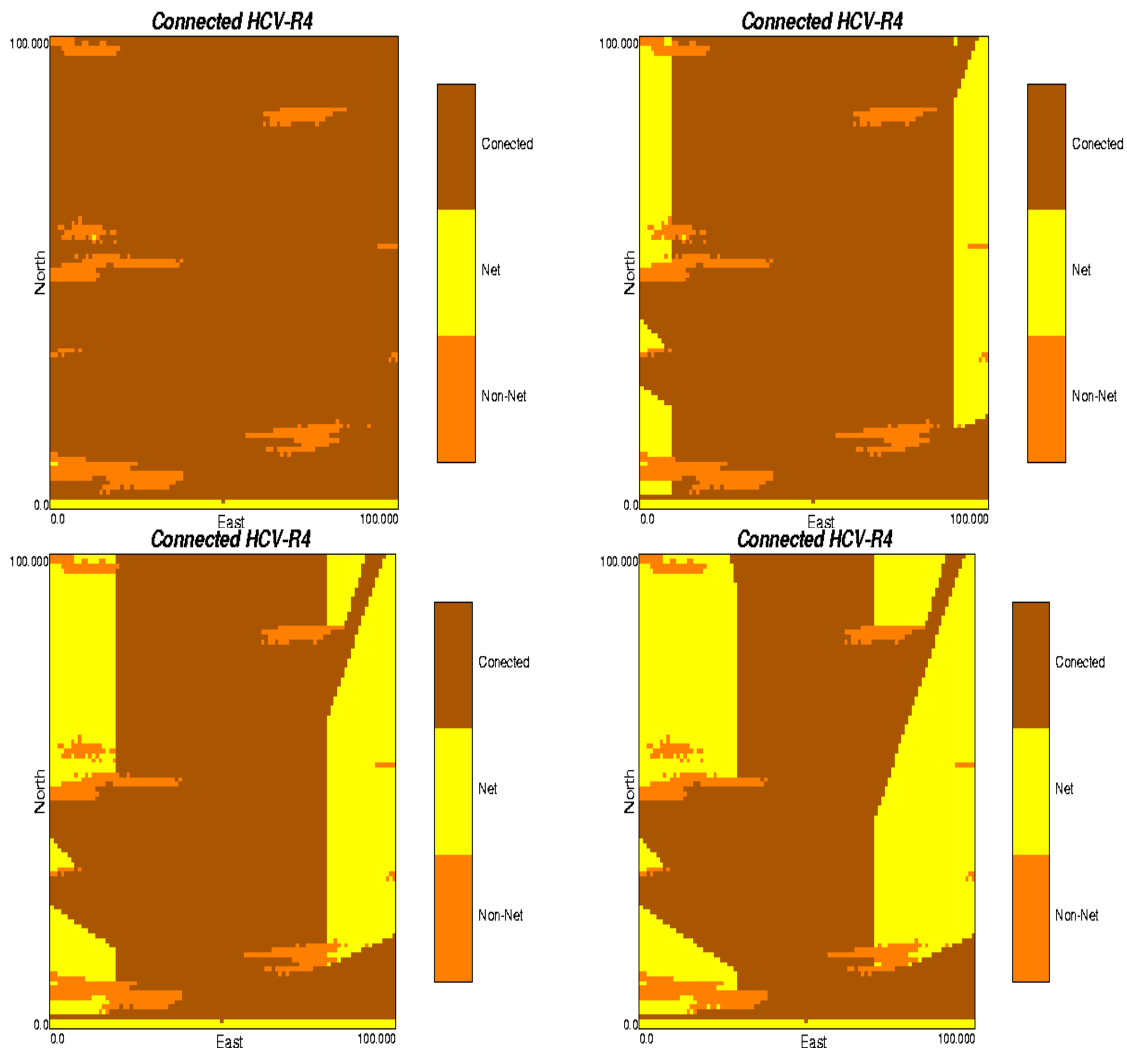

Figure 9: Examples of window sizes for Realization 4

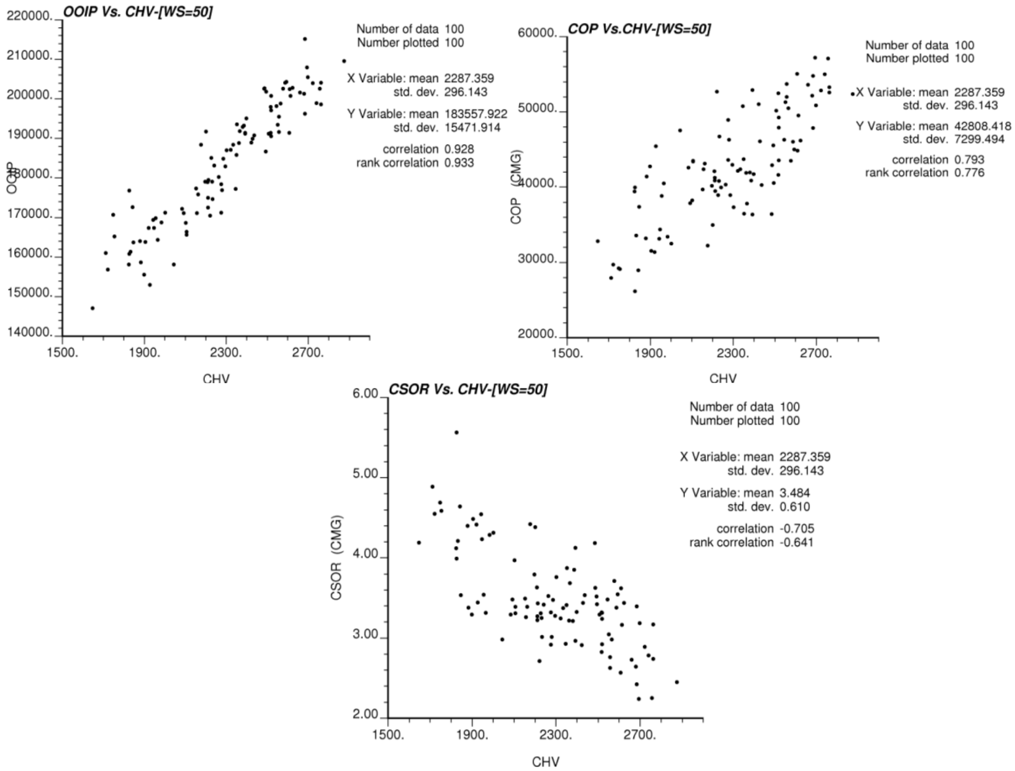

Figure 10: Plots of: (a)OOIP, (b) COP, (c) CSOR [CMG] with CHV at Window size of 50

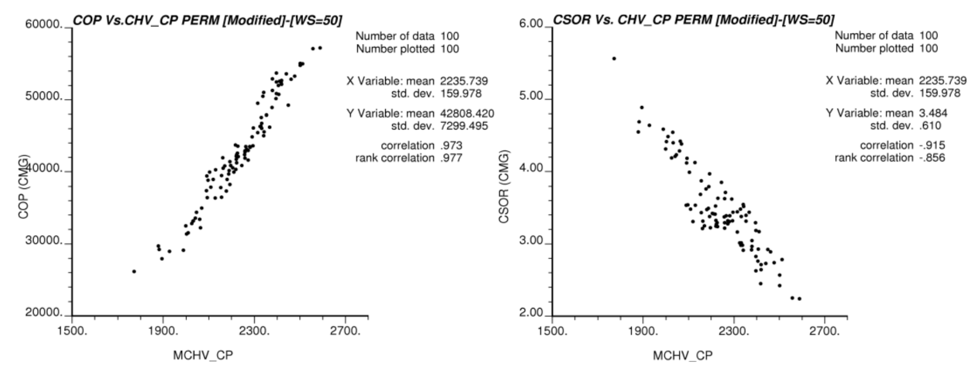

Figure 11: Plots of COP and CSOR with modified CHV