A Short Note on Optimal SAGD Pad Placement

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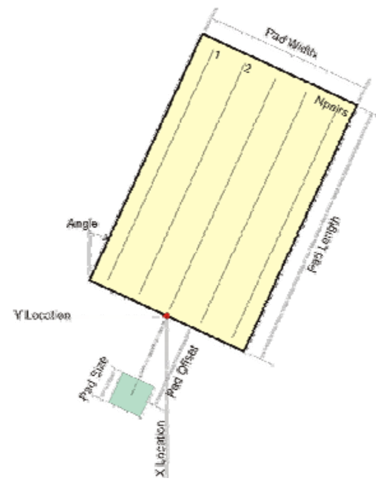
This short note addresses the placement of SAGD production pads in the McMurray formation. An optimization algorithm is developed to determine the placement of multiple pad locations to maximize the development of high production areas, account for interaction between pads, account for surface constraints, and minimize conformance issues caused by the reservoir base. The objective function, optimization approach and some preliminary results are shown. This note describes a program OptPadLoc that is in development at CCG. The program does not account for all possible considerations, but it provides an initial framework.

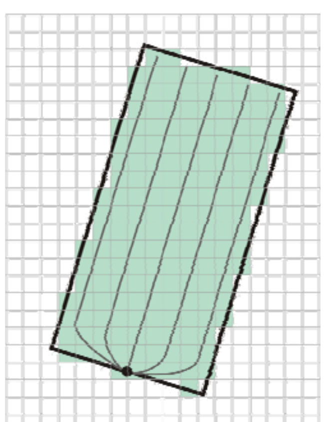
Problem Formulation

This note aims at optimizing pad locations in the McMurray Formation. The essential idea is more generally applicable to reservoir management, but the focus is thermal processes in heavy oil. Geostatistical realizations are used to characterize reservoir quality and assess uncertainty. There is a need to proceed beyond a geostatistical assessment of uncertainty to engineering design.



As illustrated schematically to the right, each pad is parameterized by an X/Y location, an azimuth angle, pad length, pad width, pad size (surface facilities that are assumed square), and a pad offset. There are additional parameters that could be considered. The optimization considers multiple pads that may have different sizes and locations. Selected pads can be frozen in the calculations and manually selected configurations can be checked.

Objective Function



The objective is to maximize the expected economic value of a particular pad design. The expected economic value is calculated with a reservoir quality variable and other modifying factors. The reservoir quality variable considered could be the thickness of net continuous bitumen or some other closely related proxy for reservoir quality. The current program will optimize over one 2-D grid of reservoir quality. It would be a small change to consider multiple realizations. The optimization takes place over multiple pads simultaneously. The reservoir quality is integrated over all of the cells *covered* by the pads, see right. The following text describes the component objective functions that have been coded in the first version of the OptPadLoc program.

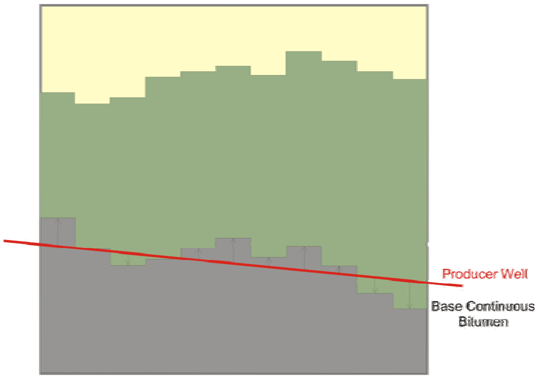
Pad drainage areas that overlap are inefficient. Perhaps some wells could be shortened or not completed in certain intervals; however, each grid cell is weighted according to the following:

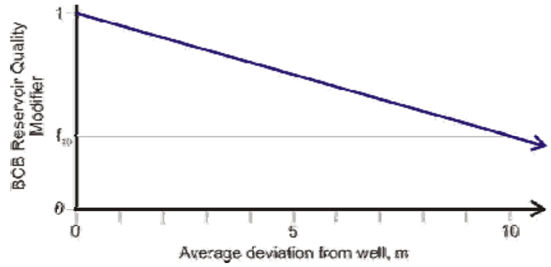
$$\text{fraction to each pad} = \left(\frac{1}{\text{number overlapping pads}} \right)^{\omega_o} \tag{1}$$

Where the exponent $\omega_o>1$ penalizes overlap. A value $\omega_o=1$ amounts to no penalty. Of course, it makes no sense to have $\omega_o<1$.

The base of the reservoir is an important consideration. If the base is rough (irregular) or if it is dipping too much along the well pairs, then vertical conformance will be compromised. Wells can be deviated (to some extent) to maximize production and minimize intervals below the base of continuous bitumen;

however, misalignment with the base incurs risk of loss of net bitumen below well and loss of productivity because well in poor quality reservoir. Vertical standoff guards against loss of productivity, but there are negative economic consequences. The following figure shows an illustration of how the base gets penalized. The quality of each pad is multiplied by a base of continuous bitumen (BCB) multiplier that depends on the average deviation from a straight well trajectory. The average is taken along each well pair in the pad.

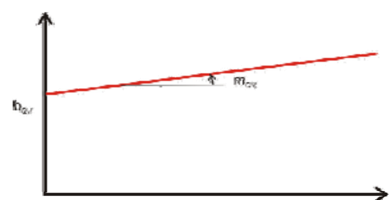




The surface location of the pads is a consideration. The pad must be away from surface water, close to roads (if possible), away from competing surface facilities, close to pipelines, avoid railways,… This surface culture must be quantified for the optimization procedure. The surface considerations must be coded into a multiplicative factor and a constant cost. This is a challenge; however, it forces a consideration and quantification of the different surface features that are important. The quality is modified as follows with the multiplicative and additive constant.

$$Q_j = \left[Q_{j,\text{unmodified}} \right] \bullet m_{surf}(\mathbf{u}_j) + b_{surf}(\mathbf{u}_j)$$

The variability of individual well pair quality within a pad affects overall performance. The variability between well pairs also affects overall performance. Ideally, we would minimize the variability within a pad (uniformly high producing well pairs) and maximize the variability between pads (sequence the high quality pads early in production). This has been introduced approximately in the present program by modifying the objective function based on the variance of quality between the pads. The user would select how to weight the variance of the pad quality.



$$O = O_{\text{unmodified}} \bullet \left(\sigma_Q^2 \bullet m_{QV} + b_{QV} \right)$$

There are other components that could be added to the overall objective function. The risk of thief zones (top gas and top water) should also be accounted for. Thief zones should be avoided. If they are encountered, then it would be best to isolate all of the thief zone above selected pads so that the operating strategy could be managed more effectively. Having a little thief zone above each pad will introduce operational problems. Other components for the objective function would be any required buffer zone between pads, minimum required quality to develop, constraints on the size and orientation of the pads, the same surface location for multiple pads, sequencing of the pads, and linking the pads through a proxy of production performance to get production predictions of steam requirements and anticipated bitumen production.

Optimization

Full simulated annealing has not been implemented at this time. The OptPadLoc program will take initial pad locations (or start with a regular grid of locations) and iteratively move the pads to maximize the objective function. A convenient mode of running the program is semi-automatically. Optimize a fixed set of pad locations, freeze the location of some obviously good pads, update the parameters of the optimization, run the program again and repeat. It is also calculate the objective function with different geostatistical realizations. This permits calculation of the uncertainty of each pad and the global uncertainty in the objective function. As stated above, the program optimizes over a single 2-D map of expected quality; multiple realizations are not used directly.

Each pad is visited in turn and a series of changes are proposed to its location and orientation. Good changes are kept and bad changes are rejected. Although the optimization is quite simplistic it has proven useful to establish the objective function and start down the path toward optimized pad locations.

Program

A GSLIB-like standalone program was written to perform the pad optimization. The code is provided for CCG members. It will be improved on an ongoing basis and an interested user is encouraged to contact the author for the latest version. The parameters are shown below:

```
1                       Parameters for OPTPADLOC
2                       ************************
3
4  START OF PARAMETERS:
5  sgsim.out                        -Input quality model
6  1  0                             -  columns for quality and base
7  0.0    5.0                       -  minimum and maximum quality
8  surface.dat                      -Input surface modifier model (optional)
9  1  2                             -  columns for factor and constant
10 start.dat                        -Input initial location file (optional)
11 2  3  4   5  0  0  0  0  0       -  cols: X, Y, ang, fix, len, wid, off, siz, np
12 pixelplt.ps                      -Input postscript file (optional)
13 OptPadLoc.out                    -Output file with summary
14 OptPadLocmap.out                 -Output file for map
15 OptPadLoc.ps                     -Output file for PS results
16 200  5.0   10.0                  -nx,xmn,xsiz
17 300  5.0   10.0                  -ny,ymn,ysiz
18 112063                           -random number seed
19 5                                -number of pads
20 1                                -half pads (1) or full (2)
21 500 200  5                       -pad length, width, npairs
22 200 100                          -pad offset and pad size (surface)
23 2.5                              -exponent for overlap penalty (>1)
24 0.5                              -f10 factor for base conformance penalty
25 0.0 1.0                          -slope and intercept for QV modifier
26 20  0.33                         -number of loops, fraction large scale
27 1.0   0.25  10   5  5  0.001     -SA schedule: t0,redfac,ka,k,num,Omin
```

Line 5 (the first actual line of the parameter file) contains the file name with the input 2-D quality variable and the base elevation. **Line 6** specifies the column numbers. <0 means that the variable is unavailable. The quality variable must be available; often, the quality is a grid of net reservoir thickness.. The minimum and maximum qualities on **Line 7** are used to mitigate the influence of a few locations with anomalous quality values. **Lines 8** and **9** specify the multiplicative and additive factors for each location accounting for the surface culture. If the file is not found, then the default is 1 and 0 everwhere, respectively. **Lines 10** and **11** specify the initial pad location file. It is optional. The X,Y location is required; other pad attributes are optional. The other variables include the azimuth orientation, an indicator to freeze (1) or not (0) a particular pad, the length, width, pad offset, pad size and number of pairs for each pad. The format of this file is the same as the output file on line 13. **Line 12** (also optional) contains the name of a GSLIB-style pixelplt PostScript file with a map of the reservoir quality. The pad locations will be drawn on top of this base map in the output file on line 15. **Lines 13, 14** and **15** are names of output files for the summary, a grid and a PostScript graphic. **Lines 16** and **17** specify the grid for the input quality and surface constraint maps. The resolution of optimization will be specified by this grid. **Line 18** contains a random number seed. The number of pads on **Line 19** is used if there is no initial file. The indicator flag on **Line 20** is not used at this time. The pad length, width, number of pairs, pad offset and pad size on **Lines 21** and **22** are the default values used for the program-chosen pads or if those parameters are not specified in the initial file. **Line 23** is the wo overlap penalty. The base modifier for an average deviation of 10 is contained on **Line 24**; the modifier for other deviations is linear from 1 at a deviation of 0. **Line 25** contains the two parameters that control the modifier for the variance between pad qualities. The number of loops on **Line 26** is used. The other parameters are not used at this time.

Examples

An output file and a couple of screenshots are shown below. These examples are entirely synthetic, but they give the reader a sense for how the program works. Each pad is described by 12 parameters (shown). The pads are sorted and numbered by quality; Pad 62 (top right) is the 62nd pad in terms of quality – there are 51 better pads in that run of the program. The original pad numbers are kept so that the user can keep track of their manual design.

```
OUTPUT Locations
12
Pad Number
X Location
y Location
Angle
Freeze: 1=yes
Length
Width
Pad Offset
Pad Size
Number of Pairs
Quality
Original Pad Number
  1  1545.0000      1265.0000       0.0 1   500.0  200.0  200.0  100.0  5  1573.3945       1
  2  1355.0000      5.0000000      -8.0 0   500.0  200.0  200.0  100.0  5  1524.5984       2
  3  735.00000      1825.0000     -19.0 0   500.0  200.0  200.0  100.0  5  1212.0747       3
  4  435.00000      365.00000      -1.0 0   500.0  200.0  200.0  100.0  5  817.24152       4
  5  585.00000      1175.0000       0.0 0   500.0  200.0  200.0  100.0  5  516.56738       5
```