Dynamic Economic Indicator To Evaluate SAGD Performance

An economic indicator called simple thermal-efficiency parameter (STEP) was developed to evaluate the performance of a steam-assisted gravity-drainage (SAGD) project. A dynamic model called STEP-D was developed for use as an economic indicator under the changing conditions of the economic limit of the instantaneous steam/oil ratio (SOR) and the price of heavy oil.

Introduction

The economics of a SAGD project is related to several production-performance parameters. The most significant are SOR, cumulative steam/oil ratio (CSOR), ultimate recovery factor (RF), and project life. STEP is based on CSOR, calendar day oil rate (CDOR), and RF for the time corresponding to an SOR of 4.

STEP's usefulness as an economic indicator was validated qualitatively as well as quantitatively. STEP was introduced to optimize SAGD operating conditions in Athabasca-, Cold Lake-, and Peace River-type reservoirs in the Alberta oil sands. This economic indicator was modified to evaluate the performance of a SAGD project under selected reservoir parameters and optimal operating conditions. STEP was found to be a useful qualitative as well as quantitative economic indicator in evaluating SAGD performance.

In reality, the economics of a thermal project depends strongly on the economic limit of SOR and heavy-oil price, p_{oil}. These variable parameters are used in the economic evaluation of field projects. In this research, a dynamic model, STEP-D, was developed for use as an economic indicator under these changing conditions. For the STEP-D calculation, the economic limit of SOR was varied from 3 to 6 and the p_{oil} from U.S. \$15 to \$30/bbl for three oil-sands reservoirs in Alberta.

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Development of a Dynamic Economic Indicator

Initially, STEP was used to evaluate the performance of a SAGD project under optimal conditions. It was proposed as a simple economic indicator, to be used instead of net present value (NPV), while determining the best SAGD operating conditions. The simulation results showed that NPV had a linear relationship with RF and CDOR, but a decreasing exponential relationship with CSOR.

For use as a quantitative economic criterion, STEP was modified, leading to the following equation.

$$\text{STEP} = \frac{(\text{RF}/0.5)\times(\text{CDOR}/0.111)}{(\text{CSOR}/3)^{2.4}}. \quad (1)$$

The economic limit for each SAGD performance parameter is assumed to be 3 for CSOR, 0.111 m^3/d/m of horizontal well length for CDOR, and 0.5 for RF. The validation of STEP as a quantitative economic indicator showed that STEP is greater than 2 in the case of an economical SAGD project. The economics calculations assume that a project is cost-effective as long as the SOR is below a value of 4.

Capital costs have not been taken into account in this procedure, on the assumption that they are similar for all the cases studied because the same well configurations and development plan are considered. NPV calculations considered only the cost of steam (\$5/bbl) and price of bitumen (\$20/bbl), at a 10% discount rate.

To develop a dynamic STEP model, STEP-D, the original STEP equation was modified as follows.

$$\text{STEP-D}=\text{STEP}\times\left(\frac{\text{SOR}_{EL}}{4}\right)^{a}\times\left(\frac{p_{\text{oil}}}{20}\right), \quad (2)$$

where SOR_{EL}=economic limit of SOR, and $a=1+1/k_v$, where k_v is vertical permeability.

For the STEP-D calculations, the previous simulation results for the three typical oil-sands reservoirs in Alberta were used. NPV has a linear relationship with p_{oil}. A linear relationship also exists with the economic limit of SOR; however, the slope of the line is higher at high reservoir k_v than at low permeability. Therefore, the exponent a was introduced into the STEP-D equation to take into account this dependence of reservoir k_v to have the highest correlation coefficient between STEP-D and NPV. Because an SOR_{EL} of 4 and oil price of \$20/bbl were assumed for the STEP calculations, these two values are used as the base case for the dimensionless STEP-D calculations.

Evaluating SAGD Performance With STEP-D

STEP-D calculations were based on the previous simulation results for reservoir-thickness sensitivity in three typical Alberta oil-sands areas: Athabasca, Cold Lake, and Peace River. Two-dimensional numerical simulations were performed. The operating pressures depended on the depth of each reservoir. The numerical grid size was 1 m in the width and thickness directions and 900 m along the horizontal well. The reservoir width was assumed to be 100 m for all cases.

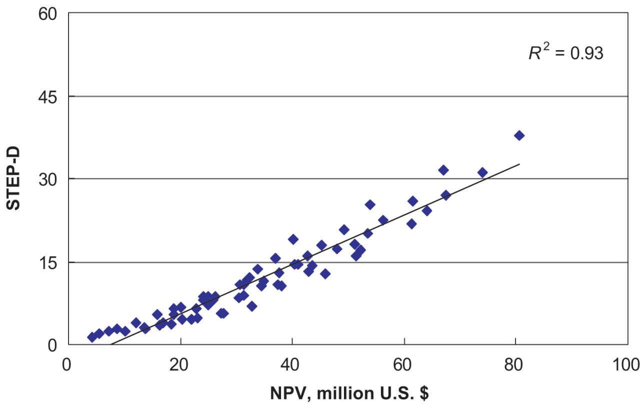

Fig. 1—Correlation of NPV and STEP-D for Athabasca-type reservoirs.

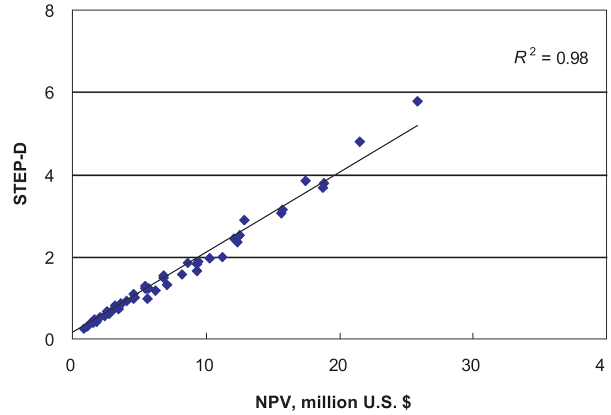

Fig. 2—Correlation of NPV and STEP-D for Peace River-type reservoirs.

Athabasca-Type Reservoirs. The reservoir parameters and operating conditions for the simulations were k_v=2.5 darcies, bitumen viscosity=1,000,000 cp, injector-to-producer (I/P) spacing=5 m, and maximum injection pressure=1500 kPa. As the SOR_{EL} increased, the NPV values increased, but the STEP values did not increase because the STEP value calculations assumed an economic limit of SOR=4. With the dynamic model of STEP, a linear relationship existed between NPV and STEP-D with a correlation coefficient, R^2, of 0.93, as shown in **Fig. 1.** Most of the Athabasca-type cases, except one having a reservoir thickness of 15 m and an SOR_{EL} of 3, seem to be economical (i.e., NPV is higher than $10 million and STEP-D is larger than 2). In the 15-m-reservoir-thickness case, STEP-D yielded a value less than 2, which was assumed as an economic cutoff for this study.

Cold Lake-Type Reservoirs. The reservoir parameters and operating conditions for the simulations were k_v=1.25 darcies, bitumen viscosity=60,000 cp, I/P spacing=10 m, and maximum injection pressure=3100 kPa. As the SOR_{EL} increased, the NPV values increased, but the STEP values did not increase because the STEP-value calculations assume an SOR_{EL}=4. The dynamic model of STEP had a linear relationship between NPV and STEP-D with a correlation coefficient of 0.95. If STEP-D must be greater than 2 for an economical SAGD project, then all the cases of reservoir thickness of 15 m were not economical. For an economical SAGD project having a reservoir thicker than 20 m, the SOR_{EL} had to be greater than 5 with p_{oil} higher than $25/bbl.

Peace River-Type Reservoirs. The reservoir parameters and operating conditions for the simulations were k_v=0.65 darcies, bitumen viscosity=200,000 cp, I/P spacing=10 m, and maximum injection pressure=4500 kPa. As the SOR_{EL} increased, the NPV values increased, but the STEP values did not increase because the STEP-value calculations assume an SOR_{EL}=4. As shown in **Fig. 2,** the dynamic model of STEP showed a linear relationship between NPV and STEP-D with a correlation coefficient of 0.98. If STEP-D is greater than 2 for an economical SAGD project, then all 15-m-reservoir-thickness cases are not economical for Peace River-type reservoirs. For an economical SAGD project having a reservoir thicker than 25 m, the SOR_{EL} should be greater than 5 for a p_{oil} of $25/bbl. If SOR_{EL} is greater than 6, a SAGD project may be economical with a reservoir thickness of 20 m at the higher p_{oil} of $30/bbl.

Correlation of NPV and STEP-D for All Three Reservoir Types. The relationship between NPV and STEP-D

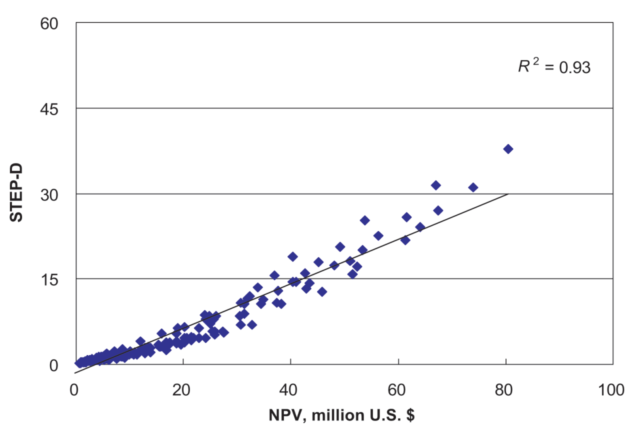

Fig. 3—Correlation of NPV and STEP-D for all the cases.

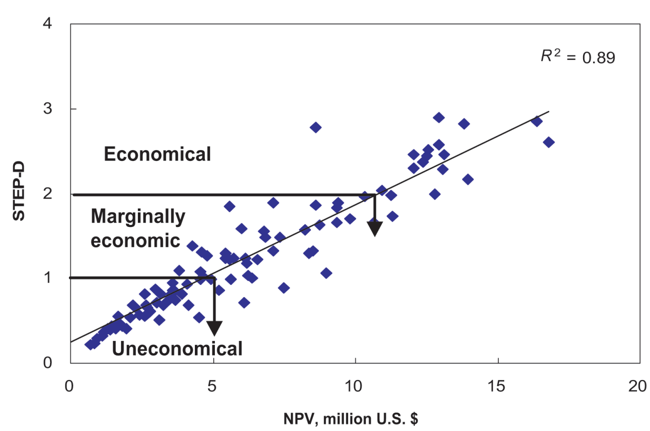

Fig. 4—Economic classification with STEP-D.

for all three areas was investigated. **Fig. 3** shows the linear relationship between NPV and STEP-D with an R^2 of 0.93 for all the cases of reservoir thickness studied in the three Alberta oil-sands areas.

The reservoir parameters required for an economical SAGD performance leading to a STEP-D greater than 2 are different for each oil-sand reservoir. Athabasca-type reservoirs, which have an average k_v=2.5 darcies, show that STEP-D is greater than 3 for a 15-m-thick reservoir. Peace River-type reservoirs, which have a lower permeability of 0.65 darcies, show that STEP-D=1 for a 30-m-thick reservoir. Cold Lake-type reservoirs, which have a permeability of 1.25 darcies, show that STEP-D is higher than 1 for a 20-m-thick reservoir. Ultimately, the k_v of the reservoir should be higher than 1.25 darcies for an economical SAGD process. Field trials of SAGD in Peace River were relatively unsuccessful, at least in part because of the low k_v. Cyclic steam stimulation was selected as the preferred recovery process for this field.

To use STEP-D as a quantitative economic indicator, the STEP-D values less than 3 were plotted against NPV for the three typical oil-sand reservoirs to determine its economic-cutoff value **(Fig. 4).** Capital costs were not accounted for in this study, so a positive value of NPV is not sufficient to imply an economical SAGD project. A previous full-scale economic evaluation proposed that STEP be greater than 2 for the economical SAGD scenarios. From the results of this study, it is proposed that STEP-D is a valuable dynamic economic indicator for a SAGD project given the following criteria: STEP-D<1 is uneconomical; 1<STEP-D<2 is marginally economical; and STEP-D>2 is economical.

Conclusions

1. STEP-D was developed as a useful economic indicator for the evaluation of SAGD performance under dynamic situations. The dynamic parameters are the SOR_{EL} and the p_{oil}.
2. A linear relationship was found between STEP-D and NPV, with an R^2>0.93 when comparing all the cases.
3. Because of varying reservoir and operating conditions, STEP-D was found to depend on reservoir thickness. This, in turn, influenced the economical performance of a SAGD project in terms of the SOR_{EL} and the p_{oil} for each reservoir type.
4. From the analysis, a SAGD project exhibiting a STEP-D greater than 2 can be considered to be economical. JPT