

Pilot Scale CO₂-EOR Project in the Mississippian: Decline Curve Analysis and Costs Associated with Mississippian Pilot CO₂ Flood

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Introduction

For the pilot-scale CO₂-Enhanced Oil Recovery (EOR) project, a total of 21,783.71 U.S. tons, equivalent to 19,803.35 metric tons or 374,462.05 MCF, of CO₂ was injected into KGS well 2-32 in the Mississippian reservoir from January 2016 through June 2016. The injector well is shown in fig. 1. The CO₂ injection was followed by water injection after the end of CO₂ injection for a better sweep efficiency. The CO₂ flood did not result in an increase in oil production until February 1, 2016. Figure 2 depicts this effect and the increased oil production as a result of CO₂ flood in the East Nelson tank battery. Figure 3 shows the volume of injected water and CO₂ from January 2016 through September 2017. Waterflood data and tubing pressures are not available after September 2017.

Decline Curve Analysis

Production rates versus time for individual wells were not available. However, monthly production rates for four tank batteries were available, so decline curve analyses were performed on tank batteries. Three tank batteries (West Nelson, Peasel, and Erker) have not shown an increase in oil production either during or after CO₂ flood (figs. 4, 5, and 6). Moreover, there is no CO₂ flood effect on the production of the wells connected to these tank batteries. Only the East Nelson tank battery has shown an increase in oil production as a result of CO₂ flood. Wells that are connected to the East Nelson tank battery are shown in purple circles in figs. 7 and 8.

A decline curve analysis and production forecast was performed on production rates for the East Nelson tank battery (fig. 2). Production rates have been updated for the East Nelson tank battery to August 2018 in Fekete Associates IHS Harmony. Decline curves were modified after updating the production rates. Decline curve by means of waterflood was modified to capture all data points except for the two lowest production rates (277 bbl/month and 243 bbl/month). The slope by waterflood is changed slightly from the last report and the slope by CO₂ flood is also changed after adding the new rates. The

analysis shows a decline rate of 6.28% per year for the waterflood curve and continuation of production to January 2025 when the economic limit of 200 bbl/month is reached. The decline rate for the CO₂ plus waterflood curve is 18.93% per year with continuation of production to October 2024.

IHS Harmony calculated the cumulative oil production for each curve in table 1 from the start of forecast to the end of forecast. The difference between the two cumulative oil productions is the cumulative additional oil attributed only to the effect of CO₂ flood (the area between the two curves) (fig. 2). The area between the curves is $53.70 - 29.27 = 24.43$ Mstb, which is the cumulative additional oil production attributed only to CO₂ flood. Cumulative oil production attributed to CO₂ plus waterflood from the start of CO₂ response to October 2024 is **53.70Mstb** (table 1). Early production history is subject to change. Therefore, the next month's history may change the slope.

374,462 MCF of CO₂ was injected in the Mississippian reservoir. Therefore, the utilization efficiency would be $374,462 \div 24,430$ bbl oil = 15.33 MCF/bbl. If ~62,385 MCF of vented CO₂ is considered, efficiency would be 12.78 MCF/bbl, excluding the vented CO₂. This efficiency is not bad for a pilot-scale CO₂ injection. The SACROC in the Permian Basin had an efficiency of 3.2 MCF/bbl for a full-scale CO₂ flood retrieved from http://petrowiki.org/CO2_miscible_flooding_case_studies.

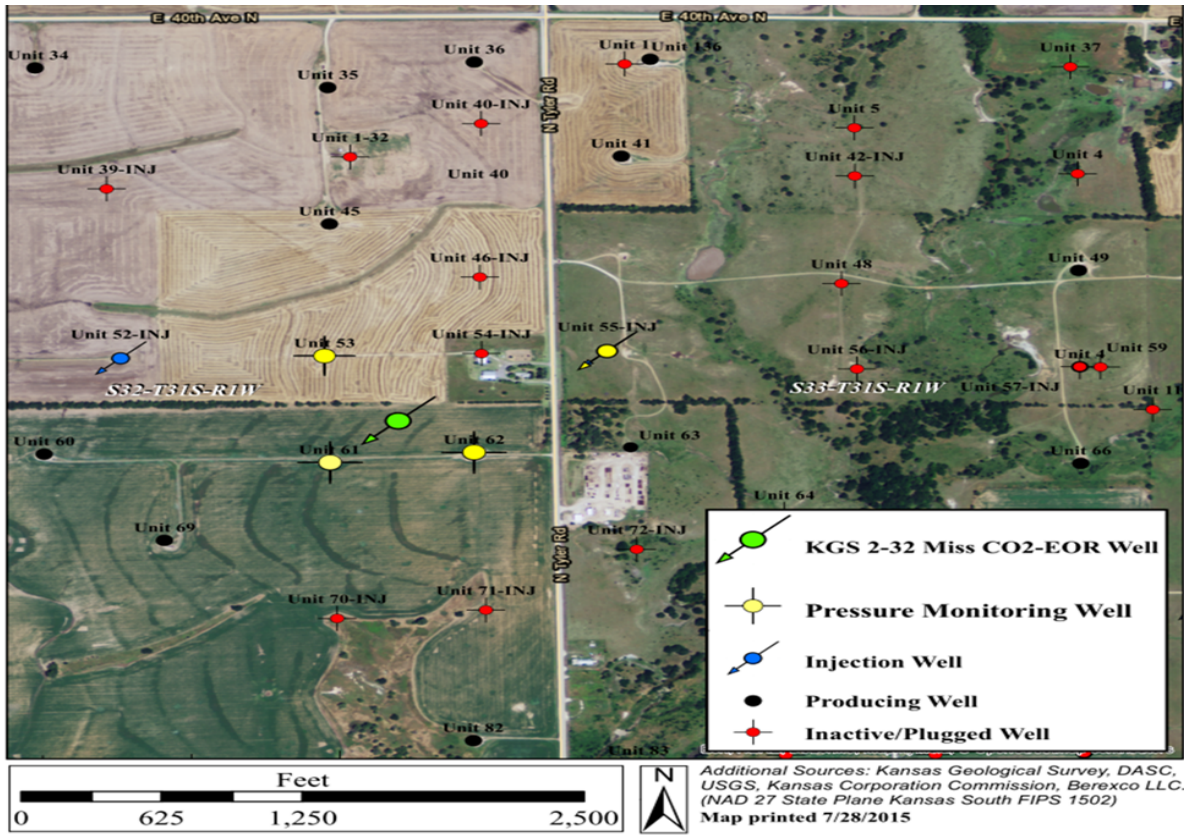


Figure 1: Injector well (KGS 2-32) and producing wells in the study area.

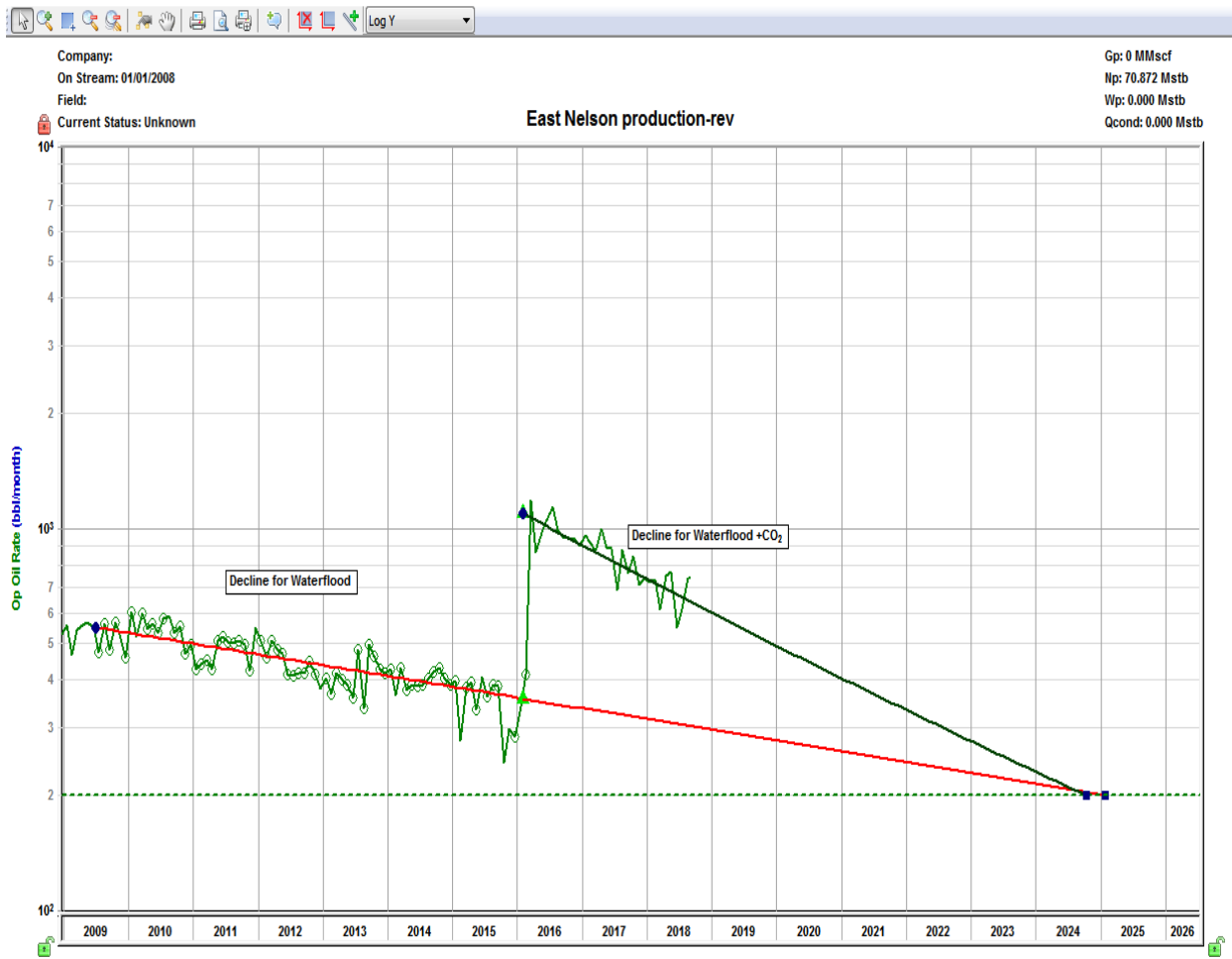


Figure 2: Decline curve forecast for CO₂ plus waterflood and waterflood in the East Nelson tank battery production area at the study site.

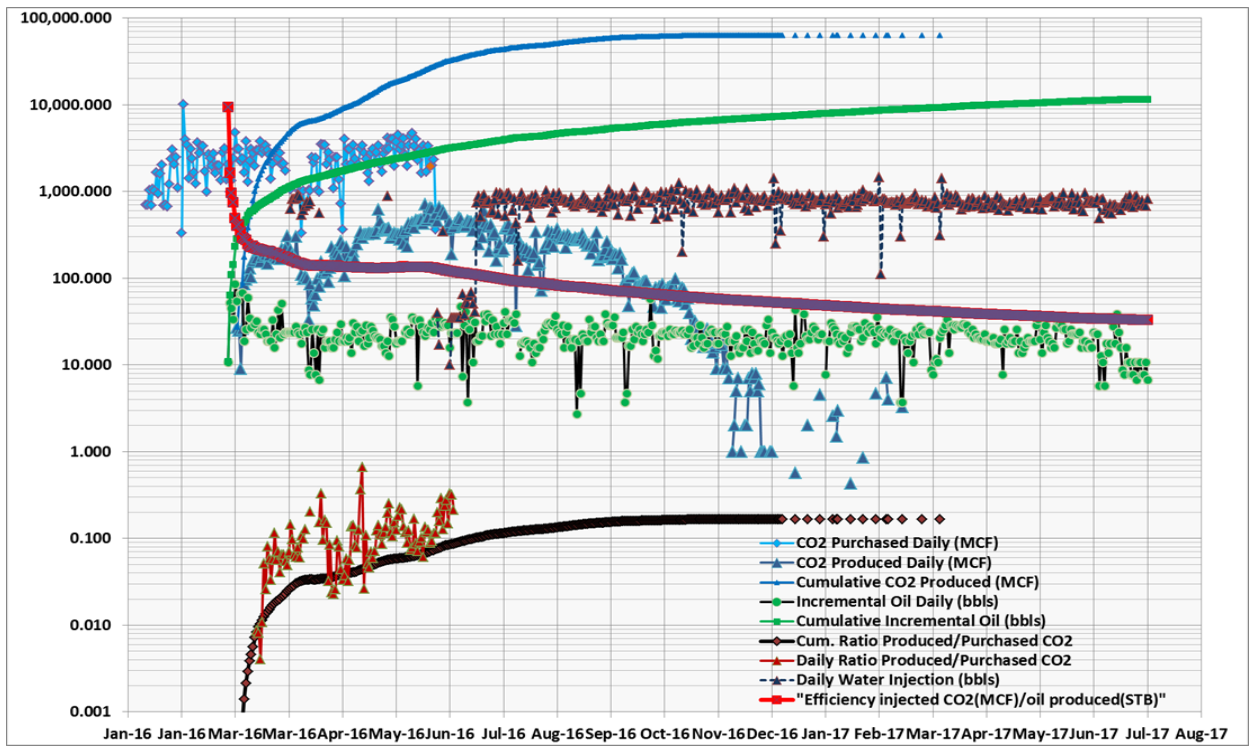


Figure 3: The volume of injected CO₂ and water, efficiency (MCF/bbl), and vented CO₂ from January 2016 to August 2017.

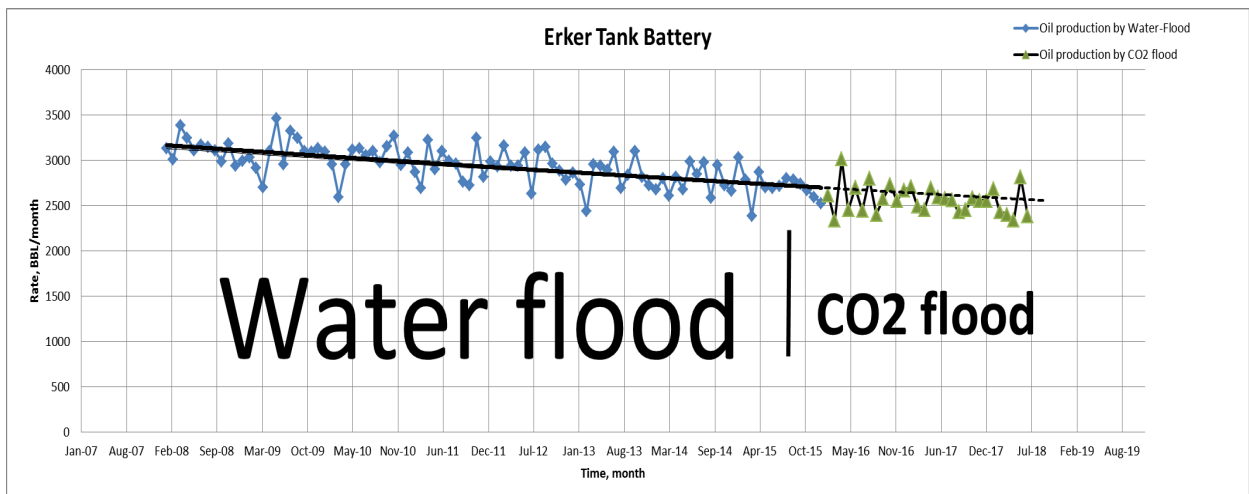


Figure 4: The decline curve for the Erker tank battery shows no additional oil production as a result of CO₂ flood.

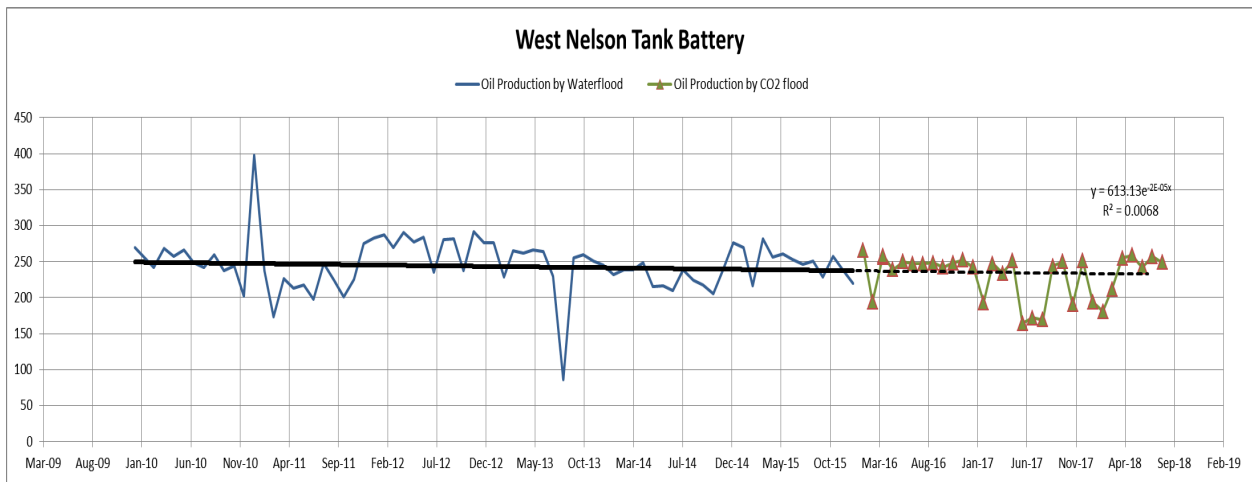


Figure 5: The decline curve for the West Nelson tank battery shows no additional oil production as a result of CO₂ flood.

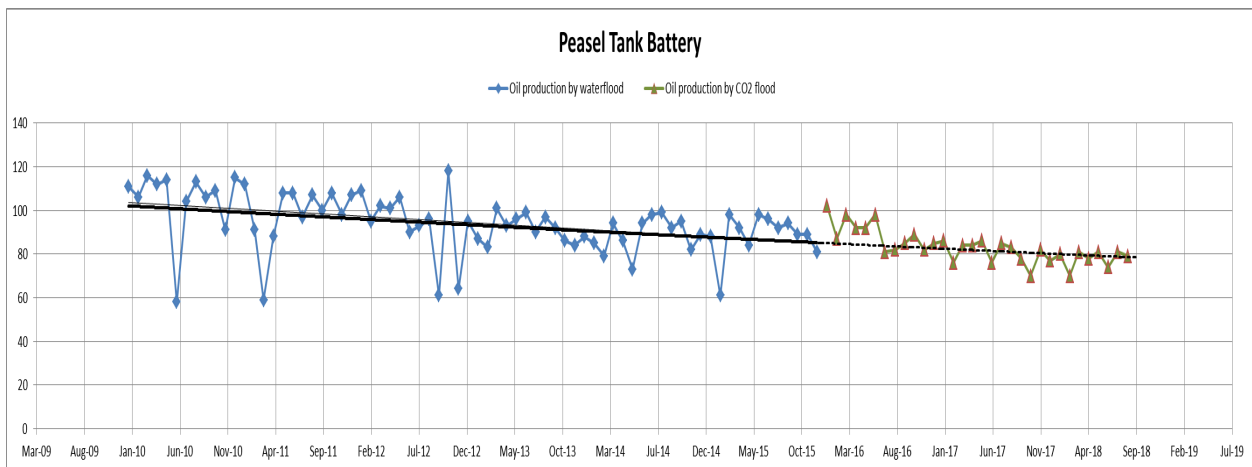


Figure 6: The decline curve for the Peasel tank battery shows no additional oil production as a result of CO₂ flood.

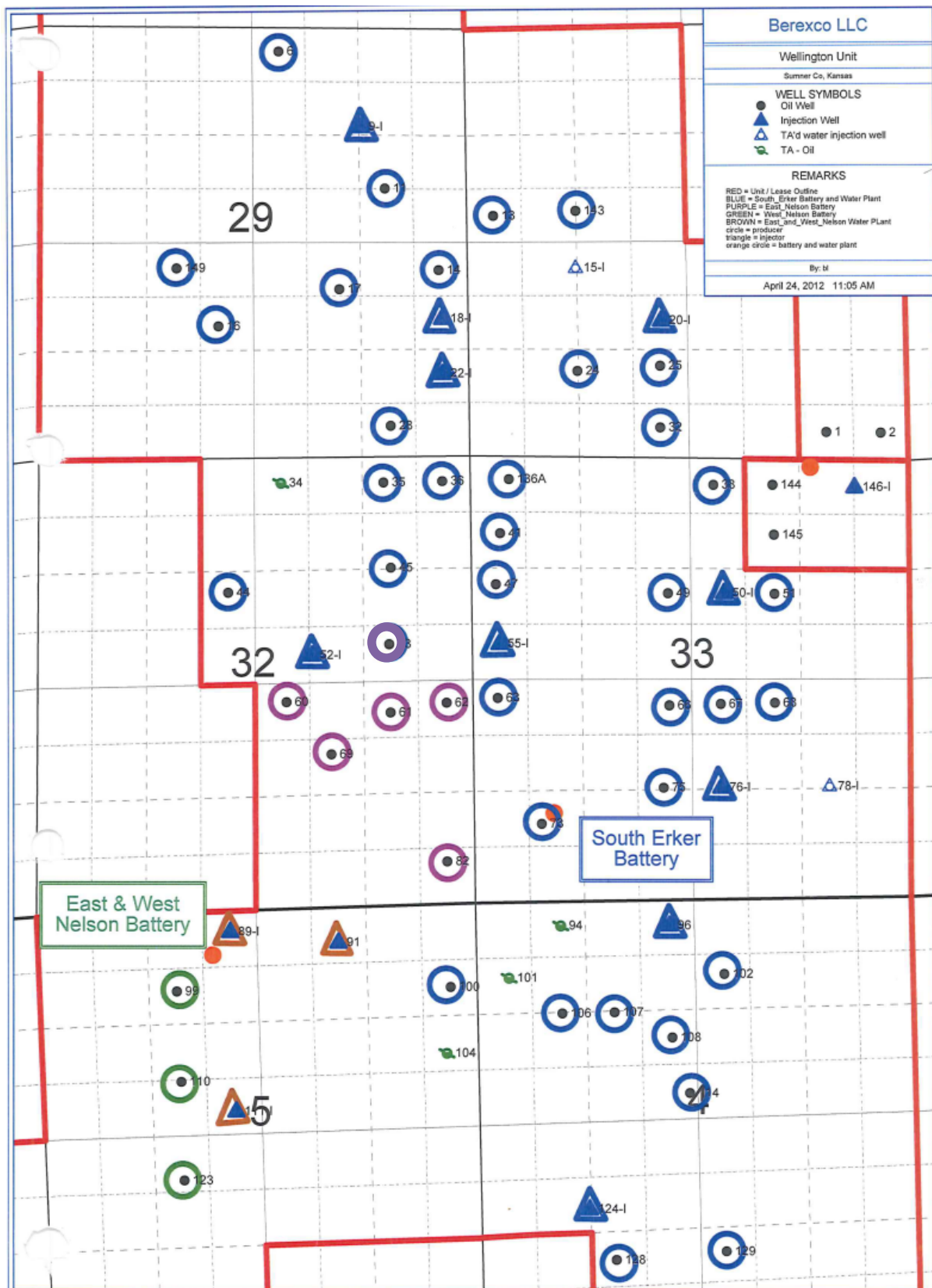


Figure 8: Wells associated with the CO₂-EOR project and their tank batteries. Wells circled in purple are connected to the East Nelson tank battery.

Table 1: Decline curve analysis results for waterflood and CO₂ flood integrated with waterflood for the East Nelson tank battery production area at the study site.

		Oil Decline							
		From Start of Forecast							
Display Name	Analysis Name	Forecast Start Date	Initial Oil Rate	Initial Cumulative Oil Production	Effective Secant Decline Rate	Final Oil Rate	End Date	Delta Cumulative Oil Production	
		MM/DD/YYYY	stb/d	Mstb	%/year	stb/d	MM/DD/YYYY	Mstb	
1	East Nelson production-rev	Waterflood only	02/01/2016	11.8	44.894	6.283	6.6	01/25/2025	29.270
2	East Nelson production-rev	CO ₂ +Waterflood	02/01/2016	35.9	44.894	18.929	6.6	10/11/2024	53.697

Note: stb/d = stock tank barrels/day; Mstb = thousand stock tank barrels

Costs Associated with CO₂ Injection

Invoices for the CO₂-EOR Mississippian project from September 2014 to August 2017 were available for analysis. This project was a Department of Energy-sponsored pilot project and all costs from drilling to completion and associated costs with CO₂ flood were charged to the DOE grant.

The costs were tabulated and classified into 22 main categories to depict different expenses, including tangible and intangible costs for the project (table 2). The cost percentage pie chart (fig. 9) shows 50% of the total costs are associated with the purchase of CO₂, which cost \$1,964,063. The next highest tangible cost is for purchased equipment, which amounts to 15% of the total costs (fig. 9). The bar chart in fig. 10 portrays costs for different categories.

If \$3,961,849 (the total for all categories) represents all of the costs associated with CO₂ flood, then the cost of produced oil would be \$73.78 /bbl.

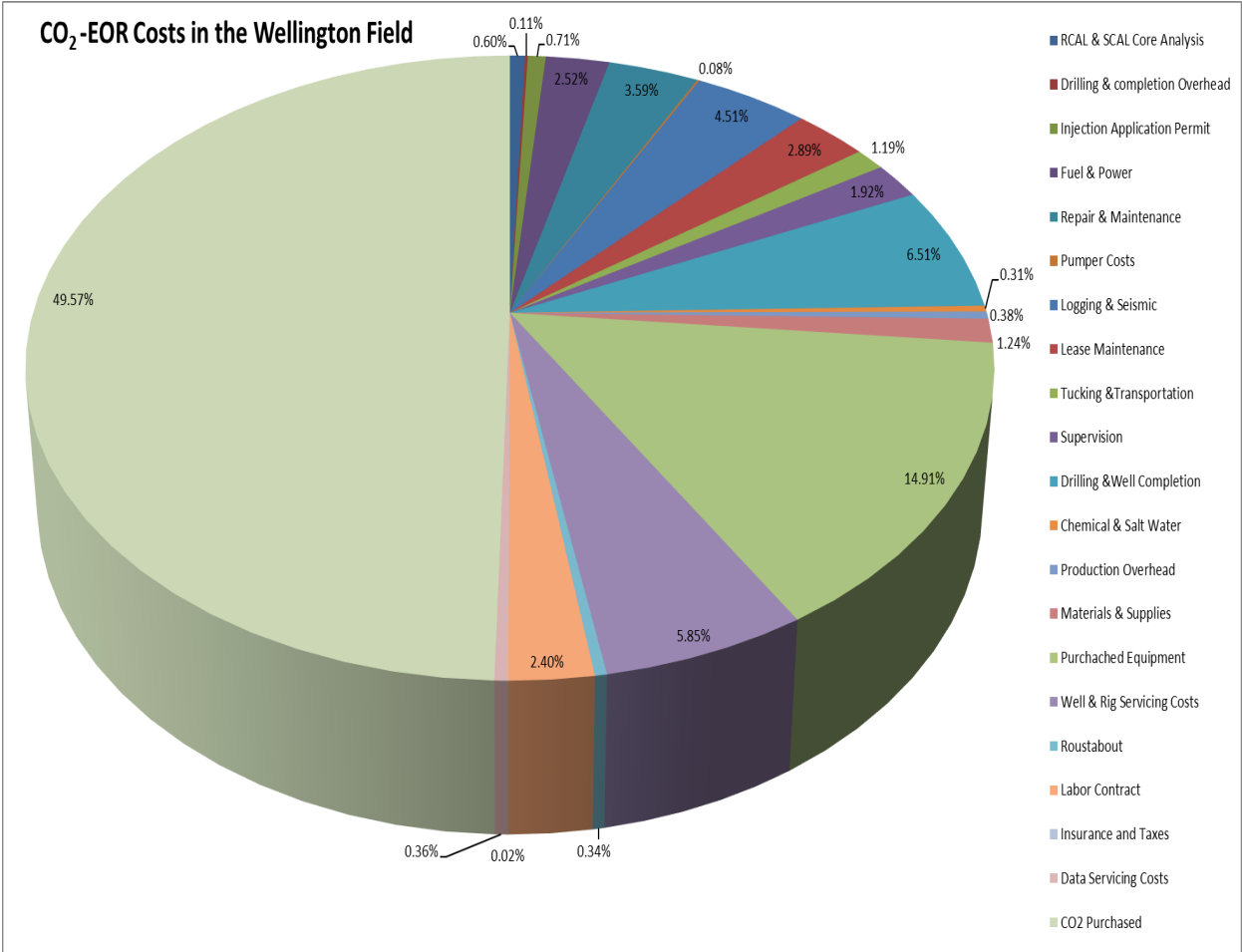


Figure 2: Percentage of costs associated with CO₂-EOR in the Wellington Field pilot project.

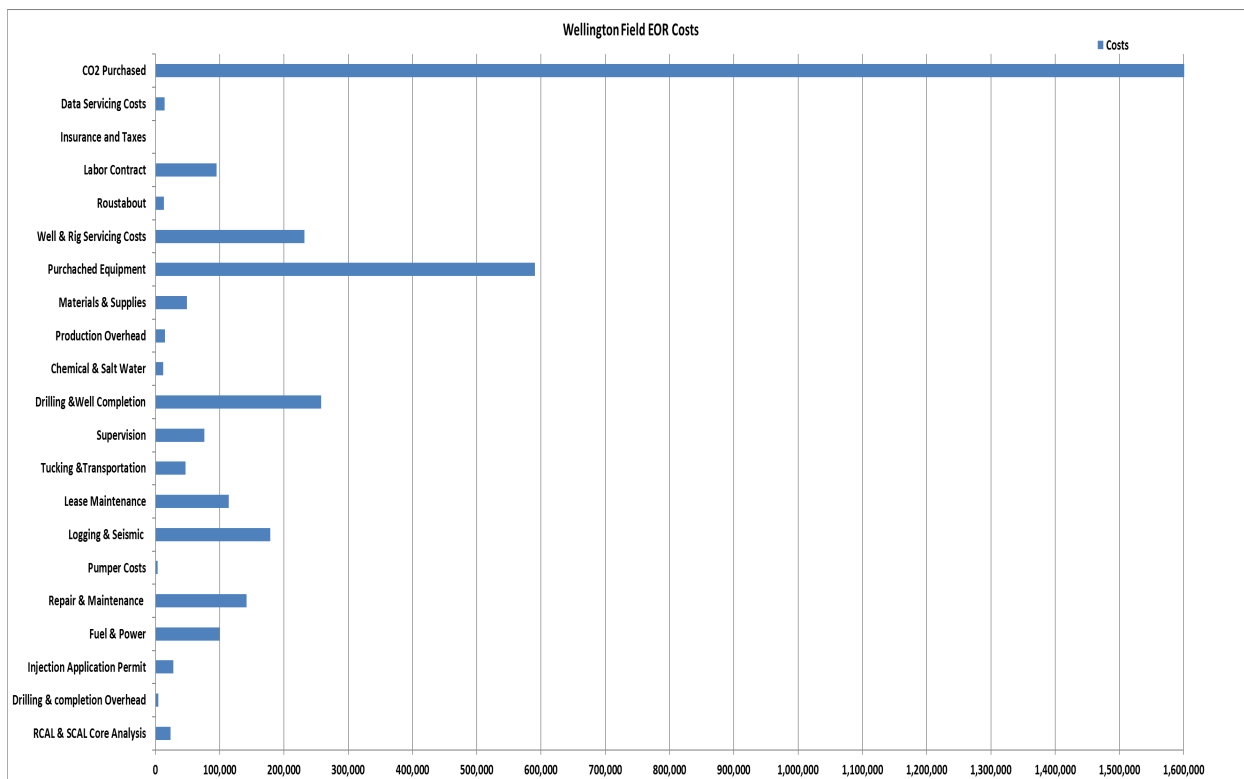


Figure 3: Costs associated with each category for the CO₂-EOR pilot project.

Table 2: Costs for each category and total costs for the CO₂-EOR pilot project.

Description	Costs	Percentage of Total
	\$	%
RCAL & SCAL Core Analysis	23,697.12	0.60
Drilling & completion Overhead	4,409.46	0.11
Injection Application Permit	28,106.58	0.71
Fuel & Power	99,750.40	2.52
Repair & Maintenance	142,048.83	3.59
Pumper Costs	3,317.86	0.08
Logging & Seismic	178,622.57	4.51
Lease Maintenance	114,344.99	2.89
Tucking & Transportation	47,123.01	1.19
Supervision	76,254.37	1.92
Drilling & Well Completion	257,857.37	6.51
Chemical & Salt Water	12,222.73	0.31
Production Overhead	15,000.00	0.38
Materials & Supplies	49,160.03	1.24
Purchased Equipment	590,695.91	14.91
Well & Rig Servicing Costs	231,645.62	5.85
Roustabout	13,415.23	0.34
Labor Contract	95,080.97	2.40
Insurance and Taxes	881.48	0.02
Data Servicing Costs	14,151.30	0.36
CO2 Purchased	1,964,063.12	49.57
Total	3,961,848.95	100.00