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Acoustic waves improve oil recovery in Permian basin

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Hydroacoustics Inc. (HAI) installed a single oil recovery tool (ORT) in the Permian basin's Turner Gregory Unit #912W injection well (TGU 912W) to improve recovery. The device began full 24-hour operations in May 2021 and a quantifiable response was identified beginning June 2021. The ORT reduced the decline rate within the area of interest (AOI) of the device to 9.5% from the area's historic 14.5%, generating a more than 30% increase in production and adding more than 100,000 bbl of estimated recoverable reserves for a 10-year period. The ORT increased the AOI's cash flow by about $500,000/yr resulting in a cumulative $3.8 million PV10 over the 10-year period, considering operating expenses and discount factor.

ORT

ORT recovers additional oil from mature reservoirs through low-frequency vibration energy from a downhole source (OGJ, Apr. 18, 2005; OGJ, Aug. 1, 2016). Acoustic energy is emitted from a transducer in the form of pulsed pressure waves that pass through liquid hydrocarbons in the formation. This application, at source frequencies generally less than 1 khz, is called sonic, acoustic, seismic, p-wave, or elastic-wave well stimulation. Explanation for the mechanism of vibrational energy recovery vary, although in general, vibrational energy dislodges oil droplets and reduces capillary forces by altering surface and interfacial tensions in the formation to coalesce and recombine into a continuous oil phase. Degassing and oil-water separation during vibrational excitation also improve recovery factors.

This type of stimulation has improved oil production from water flooded reservoirs, and examples from the literature and ORT deployments in New York and the Permian basin suggest that low-frequency stimulation can accelerate or improve ultimate oil recovery.

ORT DEPLOYMENT CRITERIA

Table 1

Secondary or tertiary recovery operation
Gas saturation preferably ≤ 20% of bulk pore volume
Producing GLR < 2,000 std cu ft/bbl (proxy for gas saturation if it is unknown)
Throughput rate range through device = 300-1000 b/d with 100% of throughput injected into reservoir. The preferred operating range is 600-800 b/d. Lower injection rates will potentially decrease the effective AOI
Average porosity ≥ 12%
Recovery factor ≤ 35% OOIP
Permeability ≥ 1 md
Dykstra-Parsons heterogeneity coefficient ≥ 0.3
Mobility ratio ≥ 1.0
Contiguous, mappable pay intervals of at least 640 acres
Preferred minimum oil production of 75 bo/d within one mile radius AOI

ORT OPERATING PARAMETERS

Table 2

Maximum operating pressure at depth, psi	3,500
Designed throughput volume range, b/d	300-1,000
Maximum operating temperature, °F.	212
Field supplied power, AC	120, 220, 480
TSS particle size, mm	≤ 200
TDS, mg/l.	≤ 100,000

TURNER GREGORY UNIT DAILY INJECTION

Table 3

Well name	Distance from TGU 912, ft	Average injectivity before ORT installation, bw/d/psi	Average injectivity post-ORT installation, bw/d/psi	First month improvement noted, 2021
TGU 912	0	0.28	0.81	May
TGU 1117W	1,190	0.12	0.31	June
TGU 917W	1,310	0.27	0.33	June
TGU 909W	1,970	0.33	0.40	July
TGU 1119W	2,500	0.23	0.46	Sept.
TGU 2505WIW	5,150	0.10	0.68	Oct.

ORT 2021-23 INCREMENTAL RECOVERY, REVENUE[1]

Table 4

Month	TGU AOI actual oil production, bbl	TGU AOI base oil forecast, bbl	Incremental oil, bbl	Cumulative incremental oil, bbl	Incremental cash flow, $	Cumulative cash flow, $	PV10, $	Cum. PV10, $
June 2021	4,163	3,623	540	540	25,872	25,872	25,872	25,872
July 2021	4,603	3,576	1,027	1,566	49,216	75,087	48,832	74,703
Aug. 2021	4,132	3,530	602	2,169	28,865	103,953	28,409	103,113
Sept. 2021	3,979	3,484	495	2,664	23,731	127,683	23,167	126,280
Oct. 2021	4,547	3,439	1,108	3,772	53,112	180,796	51,447	177,727
Nov. 2021	4,073	3,394	679	4,451	32,546	213,341	31,271	208,998
Dec. 2021	4,033	3,350	683	5,133	32,723	246,064	31,196	240,194
Jan. 2022	3,304	3,307	-3	5,131	(154)	245,911	(145)	240,049
Feb. 2022	3,117	3,264	-147	4,984	(7,082)	238,829	(6,643)	233,406
Mar. 2022	3,943	3,222	722	5,705	34,591	273,420	32,211	265,617
April 2022	3,867	3,180	687	6,392	32,942	306,362	30,428	296,045
May 2022	3,992	3,138	854	7,246	40,932	347,293	37,513	333,558
June 2022	3,787	3,098	689	7,935	33,031	380,324	30,028	363,586
July 2022	3,967	3,058	910	8,845	43,619	423,943	39,345	402,930
Aug. 2022	3,881	3,018	864	9,709	41,398	465,342	37,040	439,970
Sept. 2022	3,770	2,979	791	10,500	37,925	503,267	33,659	473,629
Oct. 2022	3,828	2,940	888	11,388	42,585	545,852	37,500	511,129
Nov. 2022	3,835	2,902	933	12,322	44,748	590,599	39,087	550,215
Dec. 2022	3,678	2,864	813	13,135	38,987	629,586	33,789	584,004
Jan. 2023	5,202	2,827	2,375	15,510	113,912	743,498	97,928	681,932
Feb. 2023	4,057	2,791	1,266	16,777	60,727	804,225	51,786	733,718
Mar. 2023	3,914	2,754	1,160	17,936	55,605	859,830	47,072	780,790

1. Field was shut down for cold weather for part of January-February 2022

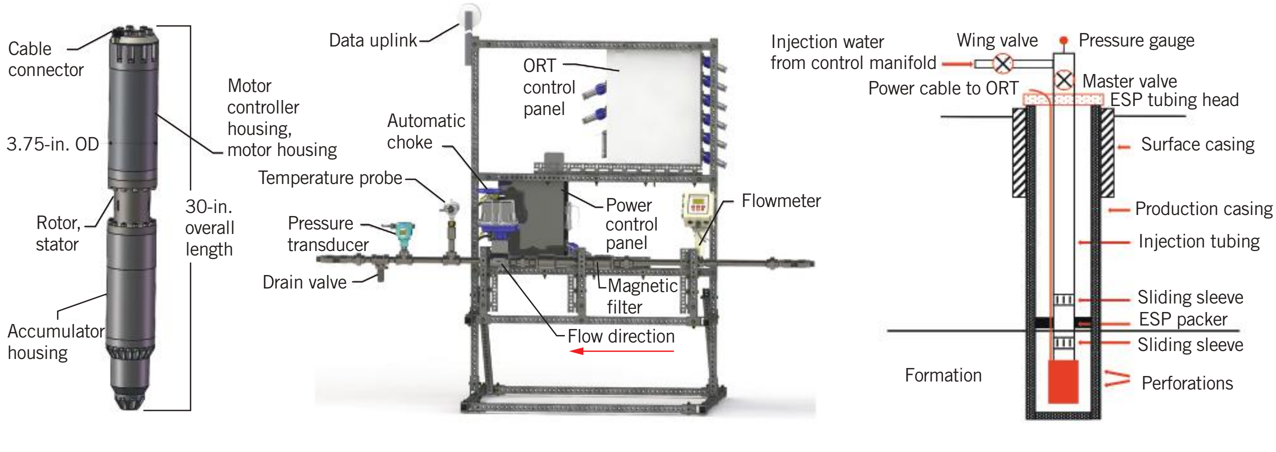
ORT 10-YEAR INCREMENTAL RECOVERY, REVENUE [1]

Table 5

Year	TGU AOI base oil forecast, bbl	TGU ORT oil forecast, bbl	Incremental oil, bbl	Cumulative incremental oil, bbl	Incremental cash flow, $	Cumulative cash flow, $	PV10, $	Cumulative PV10, $
1	40,506	50,769	10,263	10,263	492,267	492,267	492,267	492,267
2	37,282	49,572	12,290	22,553	589,531	1,081,798	535,937	1,028,204
3	29,227	41,237	12,009	34,562	576,066	1,657,864	475,964	1,504,168
4	24,989	37,319	12,330	46,892	591,439	2,249,303	444,241	1,948,409
5	21,366	33,774	12,408	59,300	595,187	2,844,490	406,414	2,354,823
6	18,268	30,565	12,298	71,598	589,887	3,434,377	366,178	2,721,001
7	15,619	27,662	12,043	83,640	577,661	4,012,038	325,904	3,046,905
8	13,354	25,034	11,680	95,320	560,243	4,572,280	287,343	3,334,248
9	11,418	22,656	11,238	106,557	539,047	5,111,327	251,338	3,585,586
10	9762	20503	10741	117298	515,221	5,626,548	218,390	3,803,976

ORT SYSTEM

FIG. 1



HAI's ORT consists of two primary components: the downhole device and a monitoring and control system at surface. The device requires a power cable in the well to connect it to the control panel and feed power to the downhole motor. A supply of filtered water is required to generate pulsed pressure waves. The control system at surface is used to convert field AC power to clean 57 volts DC, manage the flow rate into the well, start and stop the device, manage the device's operating frequency, and record pressure, temperature, and flow rate. An optional solar-battery system can be used if field AC power is not available.

The downhole device, about 3 ft long and 3.75 in. in diameter, comprises three major components: a permanent-magnet motor, rotary valve, and an accumulator. The motor spins the rotary valve at a set rpm to generate acoustic pulses at 40 hz. The accumulator acts to shape and amplify the pulse. Fig. 1 provides diagrams of the ORT, the surface control system, and a simplified wellbore diagram. Fig. 2 shows a process flow diagram and simplified field-installation schematic.

The feedstock for the ORT is produced water with total dissolved solids of less than or equal to 100,000 mg/l. and total suspended solids filtered to 200 μm or less in size. Feedstock volumes can range from 300-1,000 b/d (48-160 cu m/d). The ORT produces about 2 kw of power when operating at 600 b/d. The ORT preferred operating range is 600-800 b/d. It has a 1-mile radius effective range from the point of installation and can be utilized in any producing oilfield less than 7,500 ft deep with a producing gas-liquid ratio (GLR) of less than 2,000 std cu ft/bbl and API oil gravity ≥ 20°.

Multiple producing wells are preferred for a single ORT deployment. A general producing guideline would include about 20 wells within a 1-mile radius of the ORT-equipped well producing a preferred minimum rate of 75 b/d. Idle wells can be included in the well count, particularly if they can produce more than 3 bo/d.

Reservoir type

The technology will work in clastic or carbonate reservoirs and consolidated or unconsolidated sands. The effective range of the ORT may be decreased in unconsolidated reservoirs, although parameters such as porosity, permeability, and heterogeneity likely have a larger impact on its effective range. Table 1 lists guideline criteria that represent the basic deployment for an application of the current design. Locations that do not completely fit within these guidelines can also be considered and evaluated. Table 2 lists the current operating parameters of the ORT.

TGU application

HAI installed a single ORT in the TGU 912W injection well. TGU is a mature Clear Fork waterflood about 20 miles east of Big Spring, Tex. The Clear Fork consists of three producing intervals: Upper, Middle, and Lower with 2,200-3,300 ft total depth. Estimating the contribution of each interval is difficult since it is likely that the lower two zones may be covered with fill, as observed in the lower two zones in the TGU 912W injection well when the ORT was run into it. Due to the fill issue, the ORT was set across the Upper Clear Fork perforations.

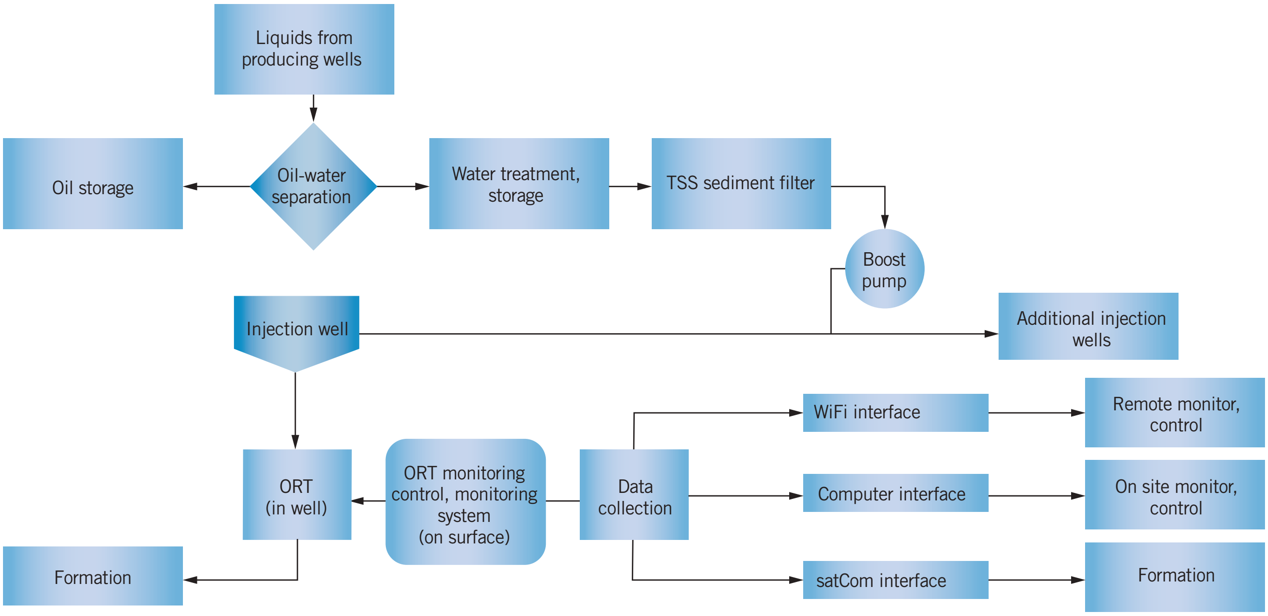
Estimated AOI for the device was defined as a 1-mile radius surrounding TGU 912W encompassing a total of 32 active producing wells and 6 active injection wells. Not all injection wells were active on a continuous basis.

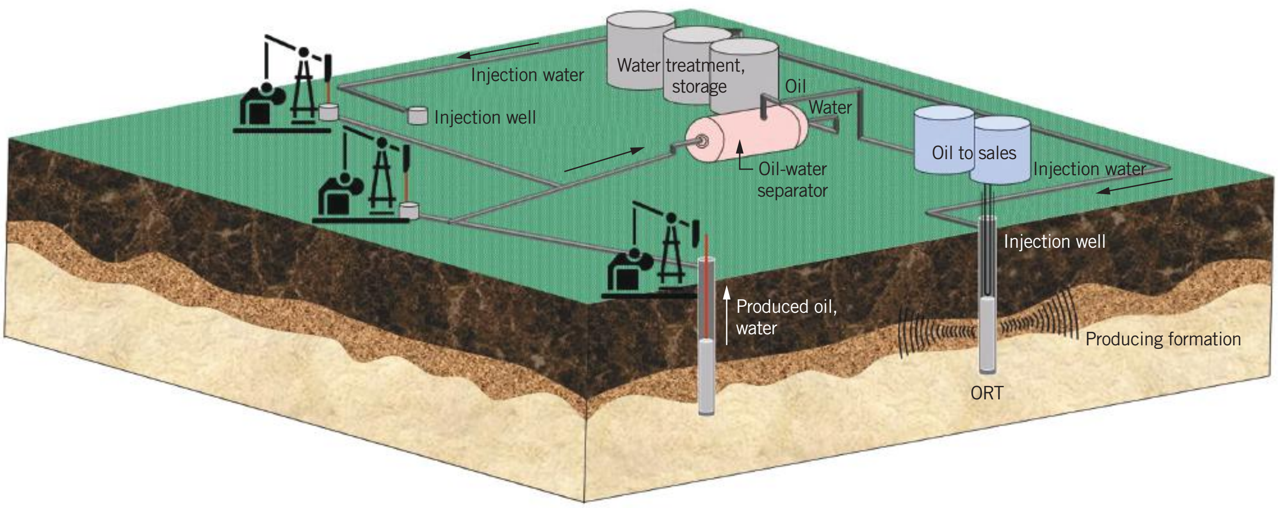
Before ORT installation, the operator supplied individual well production and injection histories from January 2015 through end-2020. Analysis of historical data showed that:

- The average decline rate in the AOI was 14.5% through July 2020, when several wells were shut in.

ORT, WATER INJECTION PROCESS

FIG. 2





• Overinjection into the asset's AOI occurred during that time frame, with cumulative overinjection of almost 310,000 bbl by July 2020. Overinjection is supported by the fact that injection well shut in pressures were 800 psi or more.

• Despite overinjection, average oil production in the AOI continued to decline to 150 bo/d by July 2020 from 320 bo/d. Per well production declined to 4.6 bo/d by July 2020 from 7.4 bo/d when several wells were shut in due to low oil prices and the pandemic.

• Only about 21 wells were producing on average from August 2020 through June 2021. Average production per well during that time was 4.2 bo/d.

• Decline rate for the AOI increased to 38% from August 2020 through May 2021.

• Average injectivities into the six injection wells within the AOI ranged from 0.1-0.3 b/d-psi.

ORT operation

The ORT began full 24-hour operations in May 2021, and a quantifiable response was identified beginning in June 2021. The operator returned shut-in wells to production by August 2021. In late October 2022, a weather-related event knocked out power to the injection well and the device. To further evaluate the device's production improvement potential, it was left downhole but shut off, and injection into the TGU 912W was re-routed to other injection wells where the ORT's operation had improved injectivity.

Figs. 3 and 4 show decline rates for the area of interest. Both the rate-time and rate-cumulative plots show a departure from the historical decline for the AOI. Before the ORT commenced full operation, the AOI had a well-established decline of about 14.5%. Once the area responded to the ORT, decline reduced to about 9.5%. Average production per well stabilized at 4.4 bo/d and the initial average production increase for the AOI over base decline was about 24 bo/d, increasing to 31 bo/d by March 2023, representing reserve additions of 117,000 bbl over the next 10 years. Production increases are compared with the 2015-2020 base decline forecast, not the increased decline rate observed August 2020 to May 2021.

Injectivity for the TGU 912W increased to more than 0.8 b/d-psi from an average 0.3 b/d-psi. Depending upon reservoir heterogeneity, injectivities for active injection wells within the AOI increased incrementally by anywhere from 30% to 100%.

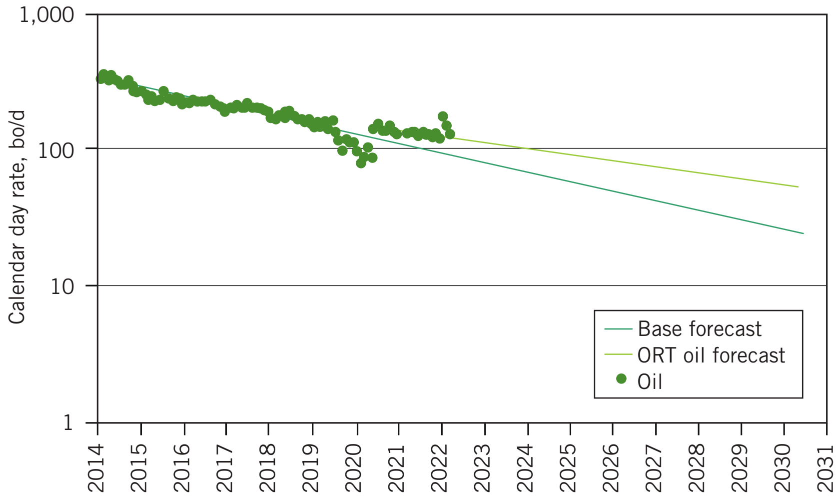
Fig. 5 shows the AOI daily oil production with respect to cumulative overinjection. The purple line plots the cumulative difference between water injected and oil and water produced. The operator reduced injection from October 2020 through August 2021, then returned to overinjection with increased injectivity resulting from the ORT's operation. In March 2022 HAI recommended that the operator balance injection and withdrawal from the AOI because overinjection was potentially reducing production.

Fig. 6 shows daily production from the AOI, daily production/well, and weighted average well count. The last is defined as total well days in operation divided by total days in a month. The figure shows that the operator followed recommendations and reduced overall water injection into the AOI to match the overall liquids production.

In addition to the production increase and reduction in decline rate, the ORT materially increased injectivity of the well in which it was installed as well as the other active injection wells within the 1-mile radius area. Reservoir heterogeneities associated with carbonate reservoirs resulted in varied improvements. The smallest improvement oc-

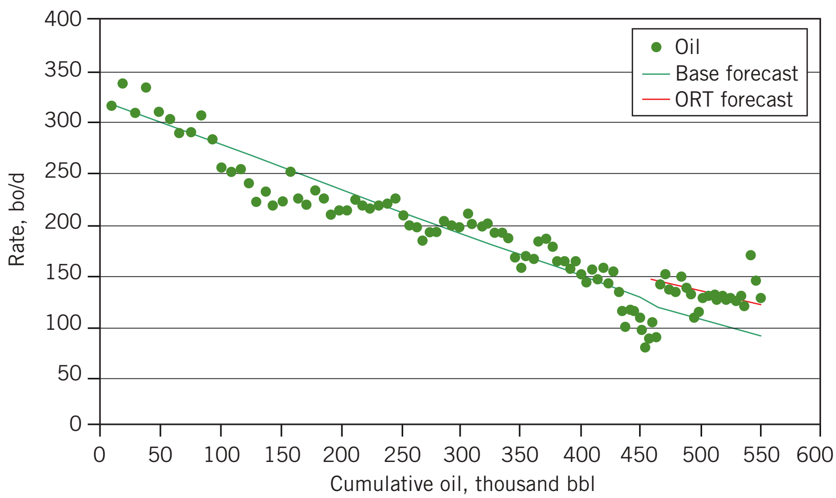
TGU AOI PRODUCTION FORECAST

FIG. 3



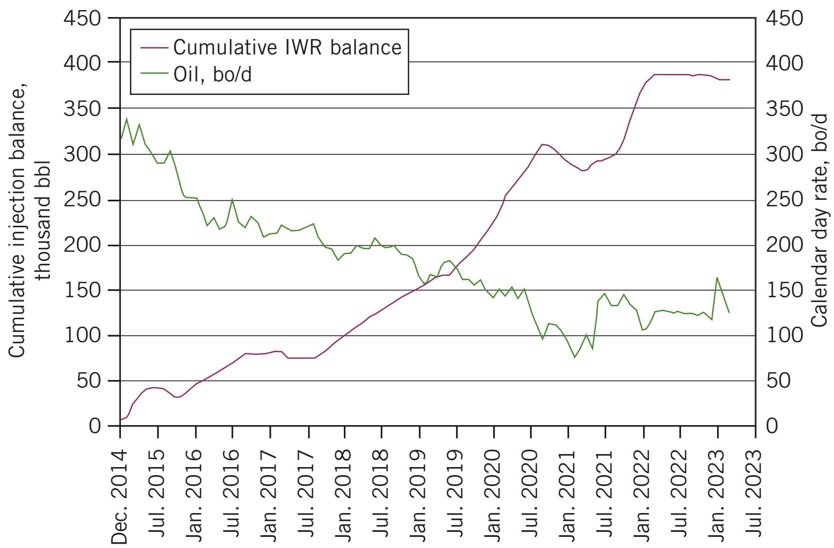
TGU AOI PRODUCTION DECLINE

FIG. 4



TGU OVERINJECITON

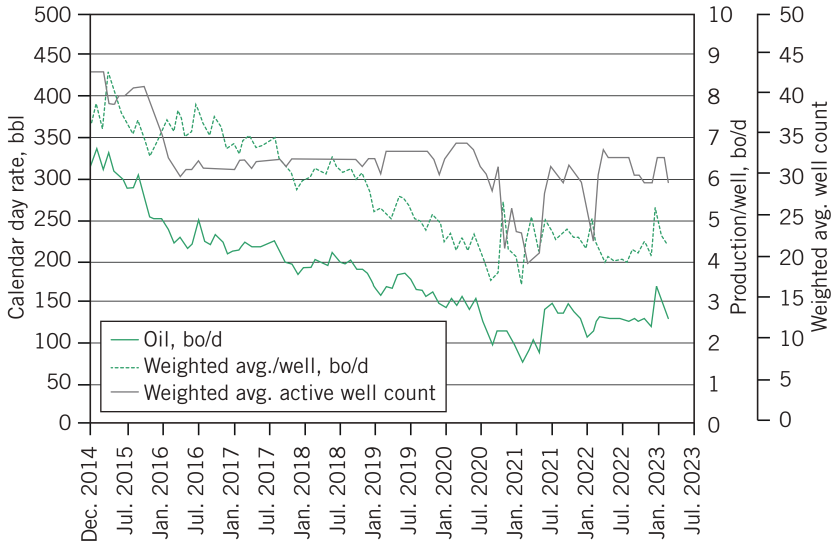
FIG. 5



curred in an injection well about 1,300 ft from the TGU 912W while the largest improvement occurred in a well about 5,100 ft from TGU 912W.

TGU AOI PRODUCTION

FIG. 6



ORT economics

Table 3 shows estimated average injectivity improvements for injection wells within the AOI with active injection from June 2021 to March 2023. Table 4 lists recovery and revenue from the ORT installation. Table 5 shows 10-year recovery estimates including PV10 (the calculation of the present value of estimated future oil and gas revenues, net of forecasted direct expenses and discounted at an annual rate of 10%). Economics were calculated using $65/bbl, 18% royalty rate, 10% production tax rate, and lifting costs of $26/bbl. The ORT maintained positive cash flow and PV10 during this time, cumulating in a PV10 of $3.8 million after 10 years. OGJ

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