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Defining the Ideal Range for Reducing Oil Viscosity and the Optimal Rate of Steam Injection for a Heavy Oil Field

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Abstract

Heavy oil reservoirs often lend themselves well to thermal enhanced recovery techniques. Traditional methods like primary production or water injection are less effective due to the high viscosity of the oil. Steam stimulation primarily aims to elevate the reservoir's temperature, thereby reducing the oil's viscosity and improving its flow properties. Steam injection stands as one of the most prevalent thermal recovery methods, commonly applied in heavy oil reservoirs. The primary goal is to validate the process for selecting suitable reservoirs, the physical mechanisms involved, and the simulation characteristics essential for steam recovery. This study establishes the optimal multiplier for reducing oil viscosity and the ideal steam injection rate for heavy oil fields.

Keywords: Enhanced Oil Recovery Techniques; Thermal Enhanced Oil Recovery; Steam Injection; Elevated Viscosity; Oil Viscosity Reduction

Introduction

Thermal Enhanced Oil Recovery (EOR) methods, also known as thermal recovery techniques, are a category of EOR processes that involve the application of heat to increase the mobility of heavy or viscous crude oil, making it easier to extract from underground reservoirs. These methods are particularly effective in heavy oil, bitumen, and certain types of oil sands reservoirs, to reduce the viscosity of oil, the thermal recovery process involves heating the reservoir. Thermal enhanced oil recovery (EOR) accounts for more than 50% of the EOR market share, with steam injection being the most widely adopted technique within this category. Another method is in-situ combustion, where a high-oxygen gas mixture is injected into the reservoir, igniting, and creating a combustion front. Steam injection is primarily employed in shallow reservoirs containing highly viscous, often heavy, crude oil. Notable examples include the oil sands in Alberta, Canada, and those in California's San Joaquin Valley [1]. Here are some of the most common thermal EOR methods.

Steam Injection (Cyclic Steam Stimulation and Steam Flooding)

In cyclic steam stimulation, steam is injected into the reservoir for a period, heating the oil and reducing its viscosity. Once the desired viscosity is achieved, steam injection is stopped, and oil production begins. This cycle is repeated.

Steam flooding involves continuous injection of steam into the reservoir to maintain high reservoir temperatures and reduce oil viscosity, enabling the extraction of heavy oil [2].

***In-Situ* Combustion:** In this method, air or oxygen is injected into the reservoir, where it reacts with the oil, producing heat and creating a combustion front. This heat reduces oil viscosity and enhances its mobility.
Electric Heating: Electrical heaters are placed in the wellbore, which then heat the surrounding reservoir, reducing the oil's viscosity. This method is effective in certain heavy oil reservoirs [3].
Solvent-Based Methods (VAPEX and SAGD): Vapor Extraction (VAPEX) and Steam-Assisted Gravity Drainage (SAGD) involve the injection of solvents, such as propane or butane, along with steam, to dilute and mobilize heavy oil or bitumen in oil sands reservoirs.

Steam injection has been commercially applied since the 1960s and is a well-established EOR technique. It works by heating the crude oil in the reservoir, which reduces its viscosity and partially vaporizes a portion of the oil, thus enhancing its mobility. This reduction in viscosity brings several benefits, including improved reservoir seepage conditions, lower surface tension, and increased oil permeability. The process of oil vaporization allows for smoother oil flow through the reservoir and, after condensation, leads to the production of higher-quality oil.

Steam injection is the most used thermal EOR technique, responsible for producing up to 30% of the original oil in certain cases. Moreover, it poses fewer environmental challenges compared to other EOR methods, making it a favorable option in regions with stringent regulations. Economic feasibility is a critical factor determining its implementation in specific fields [4] (Figure 1).

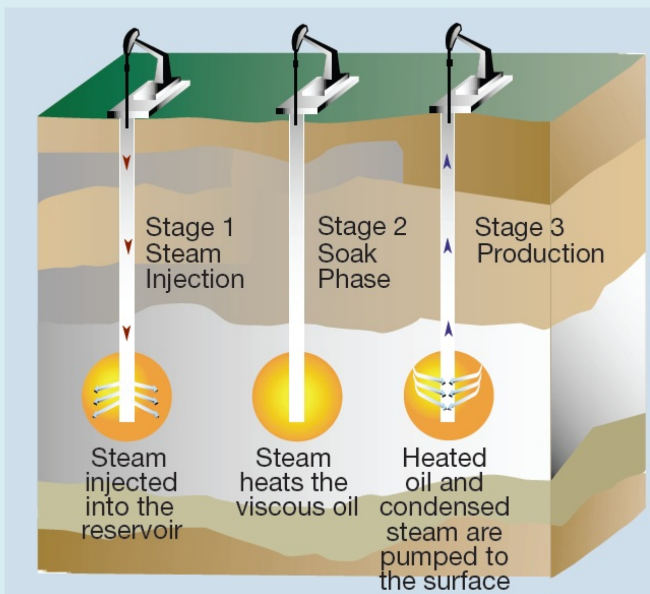

Figure 1: Cyclic Steam Simulation/Injection, Steam Soaked, Huff and Puff [5].

In the process of cyclic steam stimulation, a single well serves the dual purpose of oil production and steam injection. Initially, steam is injected for a period ranging from a few weeks to several months. This injected steam facilitates the convective heating of the oil immediately surrounding the injection well, leading to a reduction in oil viscosity [6].

Steam injection is paused once the desired viscosity is achieved, allowing heat to evenly disperse throughout the formation. This step enhances the amount of recoverable oil, Subsequently, the well can continue to produce oil until its temperature drops, and its viscosity increases once again. This cyclic process is repeated until the impact becomes negligible, and the economic limits are reached. It's important to note that most of the oil is typically extracted in the initial cycles [7].

Methodology

After conducting multiple simulation runs. The optimal steam injection rate range for this field has been identified as 1500 km^3. Beyond this value any further increase in the steam injection rate does not have a significant impact on oil production.

Determining the optimal oil viscosity reduction range and steam injection rate for a heavy oil field is a critical aspect of designing an effective thermal Enhanced Oil Recovery (EOR) project. The following steps are typically involved in this process:

Reservoir Characterization: The first step is to thoroughly characterize the heavy oil reservoir. This includes assessing factors such as reservoir depth. Temperature, permeability, porosity and the nature of the heavy oil. Understanding the reservoir's properties is crucial in determining the appropriate EOR method and parameters.

Laboratory Testing: Laboratory experiments can be conducted to determine the oil's response to temperature changes and the effect of steam injection. These tests can provide data on how oil viscosity changes at different temperatures and the impact of steam [8].

Reservoir Simulation: Using specialized reservoir simulation software. Engineers model the reservoir and the proposed EOR process. This simulation helps determine the optimal injection rates, steam temperatures and well spacing required to achieve the desired oil viscosity reduction and production rates.

Sensitivity Analysis: Engineers perform sensitivity analyses to assess how variations in injection rates, steam quality and other parameters affect the project's performance. This helps in identifying the range of optimal values [9].

Field Pilot Testing: Field pilot projects are often conducted to validate the findings from laboratory testing and simulations. These pilots involve actual steam injection and monitoring of oil production and reservoir behavior.

Data Analysis: The data collected from laboratory testing, simulation and field pilots are analyzed to determine the optimal range for reducing oil viscosity and the steam injection rate that maximizes production [10].

Economic Evaluation: A cost-benefit analysis is crucial to assess the economic feasibility of the EOR project. Factors such as the cost of steam generation, equipment installation and the expected increase in oil production are considered.

Environmental and Regulatory Considerations: Compliance with environmental regulations and the responsible use of resources, including water for steam generation are important considerations.

Implementation and Monitoring: If the project is deemed economically viable and environmentally responsible. It is implemented and performance is continually monitored and adjusted as needed [11].

In this project, heavy oil field was modeled in Tempest software. Oil viscosity multiplier was defined based on previous experiences. Sensitivity analysis was done based on various viscosity multiplier for oil. Optimal oil viscosity multiplier was determined based on this research. Then, sensitivity analysis made based on different steam injection volumes, optimal steam injection volume was obtained.

The Experimental Part

The experimental phase of this research project was carried out in the West (Qarbi) Absheron field, known for its heavy oil characteristics with oil viscosity ranging between 20-28 cP, Thermal enhanced oil recovery methods are particularly suitable for heavy oil fields. The study focused on determining the optimal range for reducing oil viscosity and the suitable steam injection rate for this specific field (Table 1 & Figure 2).

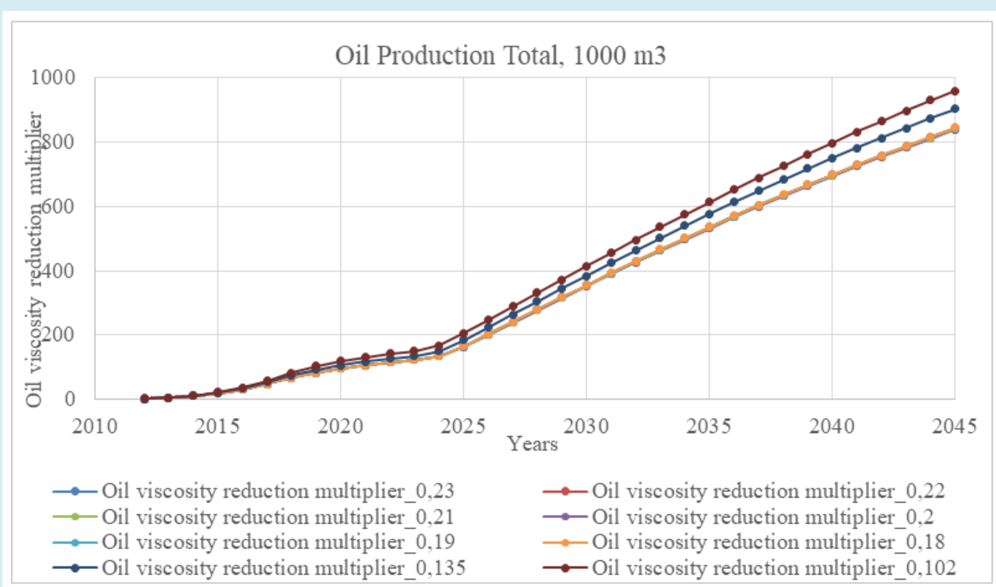

Figure 2: Establishing the Optimal Range for Reducing Oil Viscosity.

Date	Oil Production Total, 1000 m³							
	Oil Viscosity Reduction Multiplier							
	0,23	0,22	0,21	0,2	0,19	0,18	0,135	0,102
0.065648148	2.4741	2.47412	2.475	2.47789	2.47791	2.47417	2.88814	3.07049
0.065659722	4.97879	4.97881	4.979	4.98178	4.9818	4.97887	5.49999	5.73227
0.065671296	10.9067	10.9067	10.91	10.9095	10.9095	10.9068	11.6128	11.9217
0.06568287	20.1638	20.1638	20.16	20.1662	20.1663	20.1641	22.0268	22.8226
0.065694444	30.5421	30.5422	30.54	30.5442	30.5443	30.5436	33.9998	36.3158
0.065706019	48.0891	48.0892	48.09	48.091	48.0912	48.0908	53.5416	58.6602
0.065717593	67.2449	67.2452	67.25	67.2469	67.2473	67.2472	75.2534	83.7646
0.065729167	83.6247	83.6251	83.63	83.6264	83.6269	83.6272	93.5551	104.684
0.065740741	96.1899	96.1904	96.19	96.1912	96.1918	96.1927	107.098	119.661
0.065752315	106.775	106.776	106.8	106.776	106.777	106.778	118.301	131.91
0.065763889	115.685	115.68	115.7	115.681	115.681	115.683	127.657	141.939
0.065775463	123.264	123.264	123.3	123.265	123.265	123.267	135.589	150.293
0.065787037	135.146	135.253	135.4	135.497	135.615	135.736	150.442	168.526
0.065798611	163.947	164.235	164.5	164.841	165.156	165.445	184.751	206.559
0.065810185	200.631	201.007	201.4	201.776	202.167	202.528	223.831	247.907
0.065821759	238.758	239.161	239.6	239.984	240.401	240.788	263.786	289.871
0.065833333	277.384	277.81	278.3	278.677	279.114	279.522	304.288	331.642
0.065844907	315.801	316.251	316.7	317.16	317.618	318.043	344.951	373.174
0.065856481	353.336	353.877	354.4	354.964	355.506	356.004	385.008	414.351
0.065868056	390.521	391.117	391.7	392.31	392.909	393.464	424.669	455.302
0.06587963	426.932	427.577	428.2	428.873	429.529	430.142	463.638	495.693
0.065891204	462.815	463.515	464.2	464.922	465.636	466.31	502.151	535.912
0.065902778	498.161	498.909	499.7	500.409	501.172	501.895	539.86	575.51
0.065914352	532.884	533.661	534.5	535.223	536.025	536.787	576.955	614.625
0.065925926	566.838	567.649	568.5	569.271	570.101	570.894	613.619	652.943
0.0659375	600.046	600.888	601.7	602.581	603.456	604.297	649.567	690.2
0.065949074	632.461	633.347	634.3	635.141	636.071	636.959	684.022	726.58
0.065960648	664.321	665.238	666.2	667.039	667.943	668.792	717.471	762.27
0.065972222	695.451	696.33	697.2	698.051	698.915	699.729	750.223	797.247
0.065983796	725.566	726.425	727.3	728.132	729.006	729.841	782.271	831.735
0.06599537	754.708	755.6	756.5	757.379	758.292	759.167	813.589	865.569
0.066006944	783.374	784.311	785.3	786.175	787.133	788.054	844.54	898.73
0.066018519	811.809	812.789	813.8	814.753	815.769	816.752	874.921	930.45
0.066030093	839.652	840.711	841.8	842.829	843.926	844.989	903.8	960.583

Table 1: Establishing the Optimal Range for Reducing Oil Viscosity.

According to the research, optimum oil viscosity was achieved in case of 0.102 oil viscosity reduction multiplier. Total oil production was 960.583 km^3 in the beginning of 2045 year.

Based on different simulation runs. It has been defined the optimum oil viscosity reduction range for this field. It is 0.102 (Table 2 & Figure 3).

Date	Oil Production Total. 1000 m^3						
	Steam Injection Total						
	2000	1500	1200	1100	1000	900	800
0.065648148	3.07049	3.07049	3.07044	3.07044	3.07049	3.07044	3.07044
0.065659722	5.73227	5.73227	5.73223	5.73223	5.73227	5.73223	5.73223
0.065671296	11.9217	11.9217	11.9217	11.9217	11.9217	11.9217	11.9217
0.06568287	22.8226	22.8226	22.8241	22.8241	22.8226	22.8241	22.8241
0.065694444	36.3158	36.3158	36.3174	36.3174	36.3158	36.3174	36.3174
0.065706019	58.6602	58.6602	58.6599	58.6599	58.6602	58.6599	58.6599
0.065717593	83.7646	83.7646	83.7665	83.7665	83.7646	83.7665	83.7665
0.065729167	104.684	104.684	104.681	104.681	104.684	104.681	104.681
0.065740741	119.661	119.661	119.642	119.642	119.661	119.642	119.642
0.065752315	131.91	131.91	131.895	131.895	131.91	131.895	131.895
0.065763889	141.939	141.939	141.94	141.94	141.939	141.94	141.94
0.065775463	150.293	150.293	150.292	150.292	150.293	150.292	150.292
0.065787037	168.526	168.526	168.521	168.521	168.526	168.521	168.521
0.065798611	206.559	206.559	206.552	206.552	206.559	206.552	206.552
0.065810185	247.907	247.907	247.899	247.899	247.907	247.899	247.899
0.065821759	289.871	289.871	289.863	289.863	289.871	289.863	289.863
0.065833333	331.642	331.642	331.635	331.635	331.642	331.635	331.635
0.065844907	373.174	373.174	373.166	373.166	373.174	373.166	373.166
0.065856481	414.351	414.351	414.343	414.343	414.351	414.343	414.343
0.065868056	455.302	455.302	455.294	455.294	455.302	455.294	455.265
0.06587963	495.693	495.693	495.685	495.685	495.693	495.685	495.359
0.065891204	535.912	535.912	535.904	535.904	535.912	535.835	534.612
0.065902778	575.517	575.517	575.509	575.509	575.51	574.903	572.888
0.065914352	614.791	614.791	614.783	614.783	614.625	613.268	610.296
0.065925926	653.616	653.616	653.607	653.607	652.943	650.738	646.883
0.0659375	691.731	691.731	691.723	691.603	690.2	687.27	682.653
0.065949074	729.29	729.29	729.282	728.736	726.58	722.756	717.163
0.065960648	766.797	766.797	766.775	765.454	762.27	757.33	750.491
0.065972222	803.803	803.803	803.612	801.452	797.247	791.22	782.887
0.065983796	840.523	840.523	839.893	836.97	831.735	824.545	814.543
0.06599537	876.871	876.871	875.567	871.838	865.569	857.001	845.363
0.066006944	912.64	912.64	910.494	906.042	898.73	888.655	875.421
0.066018519	947.39	947.39	944.203	939.019	930.45	919.024	904.515
0.066030093	981.294	981.294	976.717	970.39	960.583	947.917	932.289

Table 2: Identifying the Optimal Range for Steam Injection Rates.

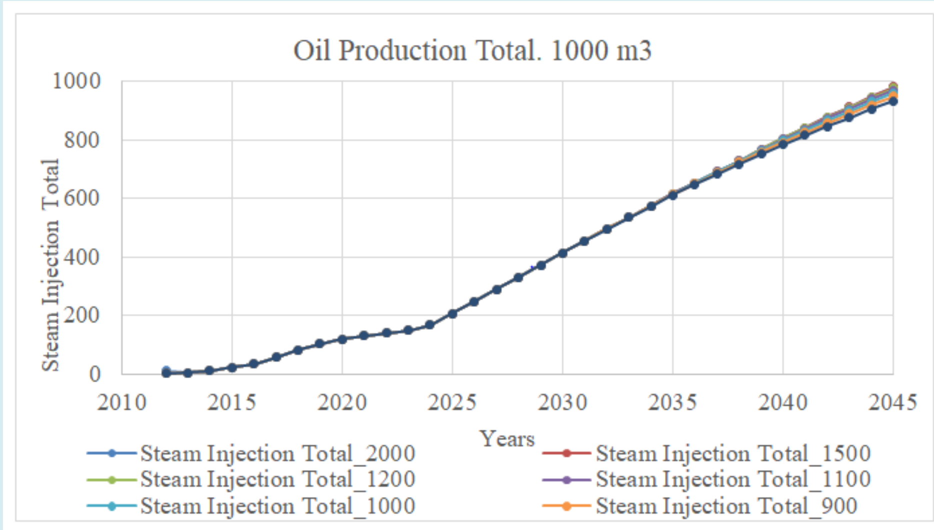

Figure 3: Identifying the Optimal Range for Steam Injection Rates.

In this stage of research, sensitivity analysis was done in different volumes of steam injection. Based on this sensitivity analysis, daily 1500 m^3 volume of steam injection is the optimal volume. After this volume, increase in steam injection doesn't increase total oil production than 1500 m^3 volume of steam injection.

Conclusion

In conclusion the selection of an enhanced oil recovery method for a specific field is of utmost importance and is primarily determined by screening criteria. Thermal enhanced oil recovery methods are particularly well-suited for heavy oil fields. This study primarily focused on determining the optimal oil viscosity reduction multiplier, which was found to be 0.102 after several cases. Additionally, it was established that 1500 km^3 of steam injection serves as a critical threshold for this field. Beyond this point, increasing the volume of steam injection does not lead to a significant improvement in oil production.

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