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ENCLOSED SOLAR ENHANCED OIL RECOVERY (ESEOR)

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ABSTRACT

Enhanced oil recovery (EOR) or tertiary oil recovery is a process used in the oil industry to extract remaining crude oil from partially-exploited reservoirs by changing the characteristics of the underground oil to improve its mobility. The current study focuses on solar thermal projects in the Sultanate of Oman at the Amal oil field located in the southern Omani governorate of Dhofar. This oil field is fully owned and operated by Petroleum Development Oman (PDO), a leading oil and gas exploration and production company in the Sultanate of Oman. In these projects, enclosed parabolic troughs are used to generate steam for thermal enhanced oil recovery, using solar thermal heating. These projects are: Amal I pilot project, Amal II pilot project, and Miraah flagship project. If combined, these three projects can supply annually about two trillion Btu (British thermal units) of heat, and can produce daily up to 2,100 tonnes of steam. The conventional heating method of burning natural gas may release annually more than 100 kilotonnes of carbon dioxide. The newly added solar steam generation system is combined with an existing natural gas combustion steam generation system, leading to a favorable reduction in the natural gas consumption by about 25%. These enhanced oil recovery projects are briefly discussed here as examples of successful sustainable practices in the oil production business and engineering.

KEYWORDS: Amal, EOR, GlassPoint, Miraah, Oman.

1. INTRODUCTION

Recent studies show a verified trend of climate change, expressed as a steady increase in temperature [1–3]. In accordance with the nonlinear relationships in psychrometrics and thermodynamics [4–7], this thermal anomaly can lead to interruptions in the natural hydrological cycle, reflected in abnormal precipitation [8–10]. An example can be the exceptional April 2024 rainstorm accompanied by hail showers and flash flooding that occurred in Oman and its neighboring country United Arab Emirates [11,12].

Limiting the climate anomalies stems from curbing radiatively active greenhouse gas (GHG) emissions 13–18, particularly carbon dioxide (CO2) 19–21 through shifting from traditional practices in engineering and businesses to sustainable ones 22–25. Examples of such sustainability shifts include phasing out systems and processes that rely heavily on burning fossil fuels 26–29, electrifying the transportation 30–36, deploying green buildings 37,38 that consume relatively a small amount of energy 39–41, investing in hydrogen 42–45 and its derivatives 46–48, exploring new high-performance power generation technologies 49–51,51,52, and utilizing renewable natural resources further 53–55.

One of the practices in need of sustainable transitioning is thermal enhanced oil recovery (EOR). It is of special importance in Oman 56,57, whose 2040 vision has 10 top-level indicators that include (Environmental Performance Index) 58,59. In the current work, a case study is presented for the sustainable transitioning of the EOR process in an oil field within Oman called Amal. In the original EOR process, natural gas was burned as the single source of heat energy to boil liquid water and convert it into hot steam suitable for underground injection to heat the crude oil and its surrounding rock layers. The modified EOR process utilizes collected solar radiation for clean steam generation, while still using natural gas for night operation. The current study provides a brief informative description of this hybrid EOR process, which was established by the company GlassPoint for the company Petroleum Development Oman (PDO), which owns and operates the oil field.

In the solar enhanced oil recovery (SEOR) technique for these projects, parabolic trough mirror concentrators 60–62 are used to collect and focus the incoming solar radiation for industrial heating, rather than for electricity generation 63–66. Liquid water is heated and it is partly boiled to produce a two-phase medium with a quality of 80% 67–69, at a subcritical temperature or below the critical temperature for water, which is 374C 70,71, and a temperature-dependent subcritical saturation pressure near an absolute value of 100 atm 72,73. This solar-generated heating agent is used to operate the solar enhanced oil recovery. The solar troughs are dynamically tilted with one degree of freedom 74–78 to track the solar radiation, and they are placed in a greenhouse-like structure for protection from harsh environmental conditions, flow-induced vibrations, and erosive factors 79,80. This protective enclosure also eases automated cleaning.

The current study can be of interest to readers and researchers working in the areas of enhanced oil recovery, solar thermal applications, and sustainability transitions. The current work aims to present a concise case study of sustainable business practices in the oil sector and innovative alternatives for engineering design and operation.

2. LITERATURE REVIEW

In enhanced oil recovery, unexploited crude oil in underground wells is pumped up with the aid of artificial methods to reduce the flow resistance of this oil and improve its extraction from the underground formation 81.

The oil recovery stages that precede enhanced oil recovery are called primary recovery and secondary recovery. In the first stage of crude oil recovery, the crude oil is naturally extracted under the initially high well pressure. In the second stage of oil recovery, the well is flooded with water or a gas to artificially increase the well pressure 82,83. The amount of oil that can be recovered during each of the three production stages depends on the properties of the crude oil itself.

Heavy oils can be defined as those having an American Petroleum Institute gravity (API) below 22.3 84. For heavy oils, enhanced oil recovery is responsible for a large portion of the oil that can be produced from an oil field, while a small amount can be produced in either the first stage or the second stage 85,86.

Heavy crude oils not only have relatively high densities but also have high viscosities, causing resistance to flow. Light oils are commercially desirable due to being easier to refine and easier to produce 87,88.

3. RESEARCH METHODOLOGY

The research methodology followed in this study is a qualitative analysis of secondary data, where information is selected, cross-validated, organized, and presented such that it facilitates the main purpose of this study, which is to provide an example of sustainable business operation in the oil industry.

The rationale for choosing this research methodology can be justified by the aim and scope of the current study, which is primarily concerned with demonstrating an attractive, successful example in the field of oil production sustainability. The scope of the current work does not include quantitative modeling or quantitative economic analysis. The work relies heavily on curating and organizing public data in the literature. Despite the presence of numerical figures in the study, their extent is limited, which makes the quantitative aspect of the study small. The presented analysis is simple without detailed mathematical expressions, making it accessible and comprehensible to a wide range of audiences without the need for specialized expertise in engineering or technology.

Part of the data accessed was made publicly available at the GlassPoint website or in published research work by GlassPoint staff 89,90. In addition, the company was approached through personal communications, and further proprietary information was obtained.

4. RESULTS AND DISCUSSION

The current section is dedicated to presenting an abridged summary of the geometric and operational configurations for the three GlassPoint enclosed solar enhanced oil recovery (ESEOR) projects in Oman. All of them are geographically located in the same zone of the Amal oil field, which is an offshore petroleum reservoir in the southern part of Oman.

The three ESEOR projects explored here are

- Amal I (pilot scale)
- Amal II (pilot scale)
- Miraah (commercial scale).

The current section is divided into three subsections. In the first subsection, a tabular comparison between the three ESEOR projects is provided. In the second subsection, graphical illustrations related to the ESEOR concept of GlassPoint are provided. In the third subsection, photographs that help in depicting the real view of the three ESEOR projects in the field are presented. Most of the displayed visual elements here (photos and sketches) belong to GlassPoint, but they are used here with their gracious permission.

4.1. *Contrasting the Three Enclosed Solar EOR Projects*

In Table 1, eight characteristics of the three Omani ESEOR projects by GlassPoint are compared. In addition, external references are provided for additional information.

It can be noticed that the large scale Miraah project was built closer to the earlier Amal I project rather than the subsequent Amal II project. For example, both the Miraah project and the Amal I project have a similar roof design that is favored in terms of reduced complexity and cost 91,92.

Table 1: Comparison between the Three GlassPoint Enclosed Solar Enhanced Oil Recovery (ESEOR) Projects in Oman.

Characteristic	Amal I	Amal II	Miraah
1. Scale	Pilot	Pilot	Commercial
2. Thermal capacity (MW)	8	8	330
3. Annual heat output (GWh)	12	12	445
4. Average daily steam output (tonne)	50	50	2,000
5. Receiver tube evacuation	No	Yes	No
6. Number of troughs	12	16	432
7. Annual natural gas savings (million Btu)	47,437	47,437	1,897,461
8. Annual CO_2 emissions avoided (tonne)	2,514	2,514	100,565
References	93–95	96	97,98

4.2. *Illustrative Sketches*

To explain the geographical location of the Amal field (and thus the three enclosed solar enhanced oil recovery projects covered here), Fig. 1 provides a useful map that demonstrates this location 99. The Amal oil field is located in the southern part of Oman, in the north of the Dhofar governorate.

Fig. 2 illustrates the layout of the parabolic trough rows within an enclosing glasshouse 101; the curved roof in the sketch corresponds to the Amal II pilot project. The looping of heated water is noticeable in the sketch, where the heat addition process is cascaded through multiple passes along a sequence of trough rows.

The structural advantage behind the enclosure concept 102 is reflected through preventing wind loads, airborne dust, and vortex shedding from affecting the reflector mirrors 103–109.

Figure 1: Location of the Amal Oil Field in Oman (© OpenStreetMap, Permission Granted Under the Open Database License 100).

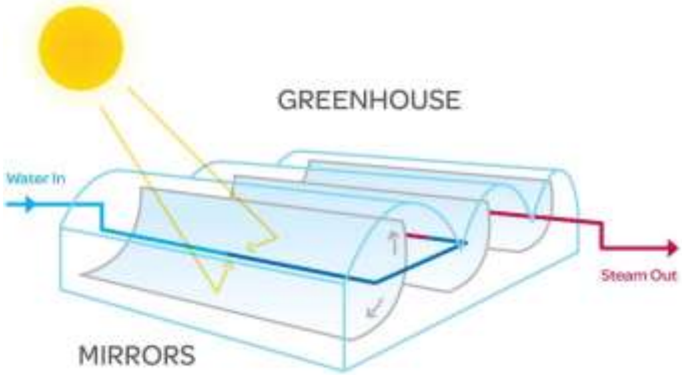

Figure 2: Illustration of the Enclosed Parabolic Trough System (© GlassPoint, Reproduced with Permission).

4.3. Photos

It can be a constructive addition to the current study to show selected real photos that effectively describe the appearance of the three constructed ESEOR projects. This aim is fulfilled in the current subsection. Fig. 3 is a photo taken for the Amal I pilot project 110. Fig. 4 is a photo taken for the Amal II pilot project 111. Finally, Fig. 5 is a photo taken for the larger Miraah project 112.

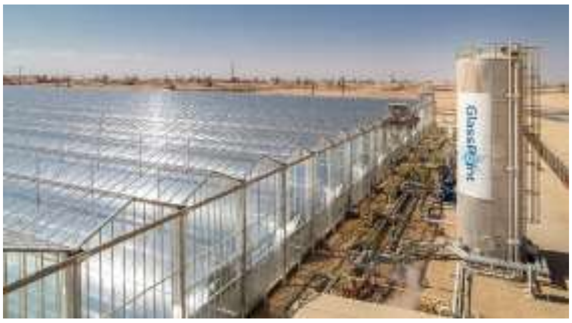

Figure 3: Aerial Photo of the Amal I Pilot Project (© GlassPoint, Reproduced With Permission).

Figure 4: Aerial Photo of the Amal II Pilot Project (© GlassPoint, Reproduced With Permission).

Figure 5: Aerial Photo of the Miraah Commercial Project (© GlassPoint, Reproduced With Permission).

5. CONCLUSION

In the current study, a quick overview of sustainable enhanced oil recovery projects in Oman was provided. In these sustainable enhanced oil recovery projects, clean solar radiation is blended with natural gas combustion as a hybrid heat source for steam generation in the Amal oil field. The introduced solar heating reduced the demand for natural gas by about 25%. The consumption of natural gas was not eliminated because of the need to burn natural gas during night operations. This reduction in natural gas consumption can be improved through altering the enhanced oil recovery process to better align with the variability of the natural heating source. However, such alteration is subject to operational conditions and the ability to retrofit existing systems.

Future work may include performing an energy analysis for switching from subcritical injection to supercritical injection and exploring how this can affect the dynamics of the overall system, including internal heat and mass fluxes. Also, the current work may be expanded by exploring the optimal operation mode such that the natural gas consumption is minimized via the introduction of thermal energy storage (TES) 113–115.

The applications of solar steam generation are not limited to enhanced oil recovery. Instead, such clean steam can be used in several applications where steam serves as a heat carrier. For example, solar steam can be used in sterilization for industrial or food processing purposes. At lower temperatures, solar steam, as a source of moisture, can also be used for humidifying.

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