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Enhanced Oil Recovery by Using Solar Energy: Case Study

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Abstract

This study investigates the steam generating potential of a solar steam generation system and the potential for utility scale implementation in Libya oil for steam demanding enhanced oil recovery (EOR) methods. The proposed system uses parabolic troughs as solar collectors. The technology is proved to be technically feasible. Solar EOR should be seen as an add-on to existing plants due to the abundance of solar energy in Libya. The System Advisor Model (SAM) model system, developed by the National Office of Renewable Energy (NRE), was used to assess the plant's active and economic performance.

Keywords

Glass Point, Steam, Solar Energy, Libya, Oil Recovery

1. Introduction and Background

In the context of climate change, the world is facing an increasing need to become more environmentally sustainable by seeking alternative and renewable sources of energy beyond conventional fossil fuels. Utilizing renewable energy sources such as wind, bio, hydro, solar, and geothermal energy is therefore pertinent in order to reach sustainability goals globally. Within the field of solar power, the most well-known technology is arguably Photovoltaic cells (PV), however there are several other usable technologies in this field. One such technology, which has received more attention as of late and which has recently become commercialized is concentrating solar thermal energy [1] [2]. This technology is conventionally used to produce thermal energy; however, this paper investigates the viability of solar thermal energy to produce steam that can be generated by recycling the underground water that accompanies processes of oil extracting. Most commonly, solar thermal energy plants are situated in warm areas with a high solar irradiance. The oil sands are oil reservoirs containing oil in the form of bitumen with a low permeability. In order to extract the bitumen, which has a high viscosity, situated at depths of lower than 25 meters, enhanced oil recovery methods are used to lower the viscosity of the oil making it easier to extract [3] [4]. The utilization of concentrating solar technology for steam production in enhanced oil recovery (EOR) has been proven in different places in the world. In Amal, Oman, a 7 MW thermal parabolic trough steam production plant for EOR has been in operation since 2013 and in California, USA, a 29 MW thermal solar tower steam production plant for EOR was operational from 2011 to 2014 [5] [6] [7]. Steam flooding is a process whereby steam is injected into a number of wells while the oil is produced from adjacent wells, as shown in **Figure 1**. For generating steam or hot water, solar energy can be used for sustainability with a direct solar heating system [8] [9].

1.1. Utility Scale System

Libya's economy is largely built on the oil and gas industry, and the economic well-being of the province depends heavily on maintaining a steady level of oil production. The industry is based on oil deposits in the sand in the northern, southern and western parts of the country. The oil fields of Libya are shown in **Figure 2**. Moreover, the oil industry in Libya is affected by fluctuations in oil prices in the global oil market, and low oil prices are devastating to the country's economy. The recent low oil prices have negatively affected many oil companies in Libya, but industries that consume oil instead of producing it thrive. For example, the plastics industry and the rest of the petroleum industries are investigating ways to invest their surplus. Enhanced solar thermal recovery could be a good and economical alternative. In this paper, the possibility of implementation of the solar steam generation system is shown on utility scale and extraction techniques that can be used.

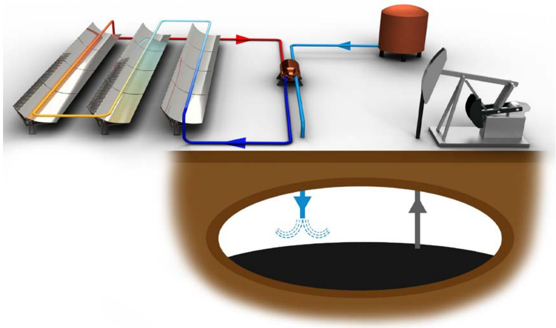

Figure 1. Solar enhanced oil recovery (EOR).

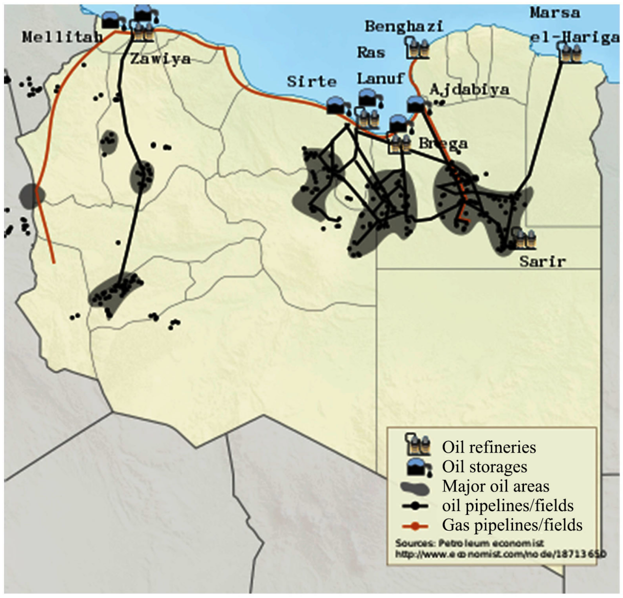

Figure 2. Libya's oil map.

1.2. Libya's Oil

Libya's oil reserves are the largest in Africa, ranking ninth among 10 countries with the world's largest proven oil reserves with an estimated rate of 46.4 billion barrels (7.38 × 109 cubic meters) by 2010. The average daily production during 2010 was 1.65 million barrels (262 × 103 cubic meters/day), where reserves are estimated to last for 77 years if production continues at the current rate and unless new oil wells are discovered. Libya is an attractive region due to the cost of oil production (up to a dollar a barrel in some fields) and its proximity to European markets. The Libyan state faces a challenge to keep production in full-grown fields while exploring and developing discovered fields. The majority of Libyan territory remains undiscovered as a result of previous sanctions and disputes with foreign oil companies. Most of the Libyan oil (85%) is exported to European markets. Libya's oil exports to the EU until 2010 were 11% or 403 million barrels making it the third largest source after Norway and Russia [10]. The cumulative production rate during 2009 was 27 billion barrels, which constitutes 65% of the reserve. Libya began oil exploration after the oil law of 1955. The National Oil Corporation (NOC) is Libya's largest oil company and is responsible for exploration and export contracts [11].

1.3. EOR Methods

Many EOR methods have been used in the past, with varying degrees of success, for the recovery of light and heavy oils as well as tar sands. A general classification of these methods is shown in **Figure 3** [12] [13]. Thermal methods are primarily intended for heavy oils and tar sands, although they are applicable to light oils in special cases. Non-thermal methods are normally used for light oils. Some of these methods have been tested for heavy oils; however, have had limited success in the field. Above all, reservoir geology and fluid properties determine the suitability of a process for a given reservoir. Among thermal methods, steam-based methods have been more successful commercially than others. Among non-thermal methods, miscible flooding has been remarkably successful, but the applicability is limited by the availability and cost of solvents on a commercial scale. Chemical methods have generally been uneconomic in the past, but they hold promise for the future. Among immiscible gas injection methods, CO2 floods have been relatively more successful than others for heavy oil [14].

2. Concentrating Solar Power Plants (CSP)

CSP plants provide energy with high temperatures which is used to run conventional power cycles such as the steam turbine, gas turbine and Sterling engine. Although CSP plants are used mostly for electricity generation, they can be used in many industrial applications. There are many different applications for CSP systems. One of the most important boundaries for choosing the most suitable technique for any proposed application is the operating temperature. For example, in applications which are used to run temperature is above 600˚C, the suitable technique is the central solar tower [15]. Other systems include:

- Solar tower system.
- Parabolic dish-engine.
- Liner Fresnel system.
- Parabolic trough system.

The advantages of Glass Point's technology (enclosed trough technology) over other solar designs are that, Glass Point technology is the only solar thermal design that provides the following:

- Delivering steam at costs competitive with natural gas. Because it covers more space (about 98% of land coverage), as shown in **Figure 4**.
- Proven to withstand harsh oilfield environment.
- Equipped with a proven, automated washing system.
- Developed using oilfield best practices [16].

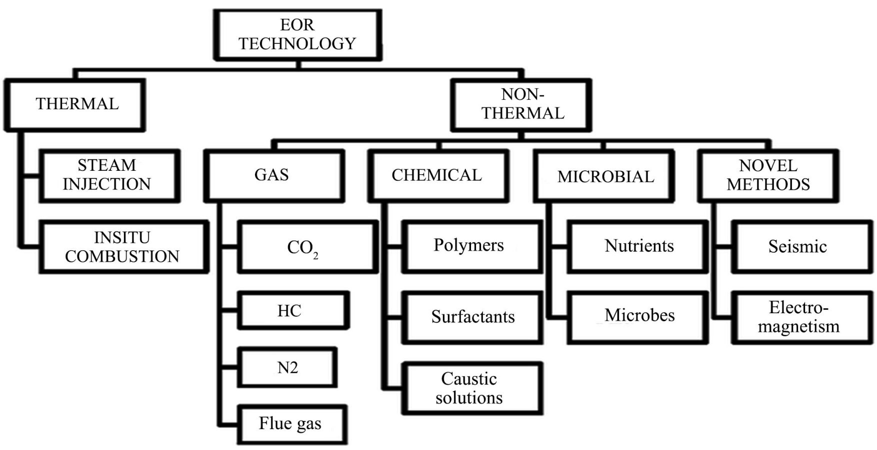

Figure 3. Classification of EOR methods.

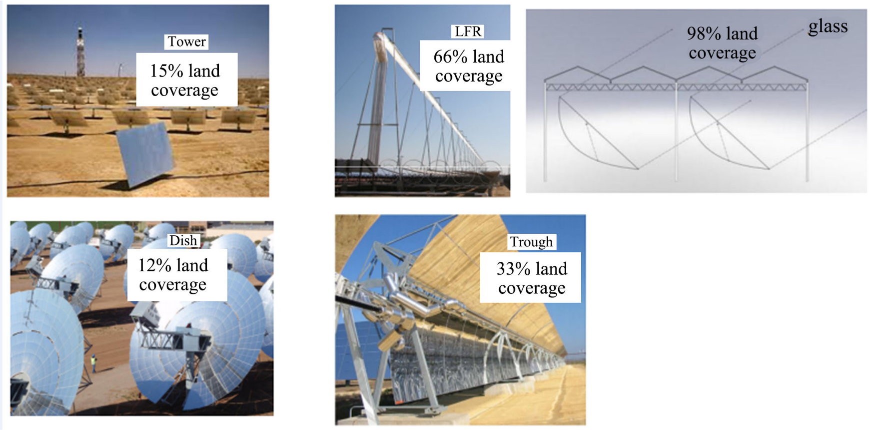

Figure 4. Types of concentrated solar collector [17].

3. Parabolic Trough Technologies Applied

In solar thermal power plants, the collectors are usually used to generate steam to power a thermodynamic cycle. The steam can be generated directly into the absorber tube. This technique is called Direct Steam Generation (DSG). Another technique is the use of a Heat Transfer Fluid (HTF) to transport solar thermal energy from the collectors to a heat exchanger where steam is generated. Enclosed trough represents an entirely new approach to the design and construction of concentrating solar collectors [18] [19]. The Enclosed trough system is protected by a glass-skinned structure, essentially a simplified agricultural greenhouse. The subject plant has a solar field footprint of 17,280 m^2 with a peak output of over 7 MW thermal. Referring to **Figure 5**, lightweight parabolic troughs are suspended within the glasshouse. The agricultural greenhouse industry has delivered over 30,000 hectares of glasshouse systems over the last few decades, and they are installed worldwide over a wide range of climates. They are available at low cost, and by providing structural support and isolating the solar collectors from wind and moisture, substantially reduce the total cost of the solar energy system.

4. Methodology of the Study

Libya is located between latitudes 20˚N - 39˚N and longitude 10˚E - 25˚E at the center of North Africa. 88% of Libya's area is desert. According to the Institute of Thermodynamics Engineering, Germany, the direct natural solar radiation varies from 1900 kWh/m^2 a year in the northern part of the country up to 2800 kWh/m^2 a year in the south-eastern Part [20]. Since concentrated solar power collectors are only economically applicable in regions where the solar radiation is up 1800 Kw/m^2 a year [21]; therefore, all the regions of Libya meet values that are higher than this value of solar radiation unlike the southern parts of the country. The plant is expected to produce 70 GW/year, and the design details are illustrated in **Table 1** and **Figure 7**. The plant was supposed to operate on a VP-1 Thermion heat transfer fluid as a heat transfer fluid.

Figure 5. Photo of the enclosed trough system facility installed in the Amal oil field, Oman [17].

Table 1. Design parameters of the proposed parabolic trough power plant by SAM program.

Characteristics	Value
Total plant capacity	25 MW
Total land area	280 × 188 m
Steam delivered	958 barrels of steam per day 152 tons of steam per day
Number of loops	17
Single loop aperture	5248 m^2
Solar multiple	2
Number of washes per year	63
Rated cycle conversion efficiency	35%
Water usage per wash	0.7 L/m^2 aperture
Row spacing	15 m
Number of field	2
Receiver type	Schott ptr 80
Absorber tube inner diameter	0.076 m
Absorber tube out diameter	0.08 m
Absorber material type	304 L
HTF type	Vp^{-1}
Design loop outlet temperature	293˚C
Design loop inlet temperature	391˚C
Full load hours	6 h
Storage type	Tow tank
Storage fluid	Hitec solar salt
Tank diameter	17.0369 m
Tank height	20 m

Libya the measures that effect evaluating the practicability of founding a site for the utilizing concentrated solar technology is the annual conditions of the weather. A location, at 32.19˚ longitude north and 20.15˚ latitude east, on the northern coast of Libya was nominated for the study because of the strength of the solar radiation at it. The conditions of the study were at temperature of 24.7˚C and mean wind speed of 3.4 m/s, and the evaluation was done by using SAM software [22]. The average energy that is resulted at that location a month is shown in **Figure 6**.

Figure 7 shows the layout of the solar steam plant system including its components. This layout uses the two-tank direct thermal energy storage. This Process Flow diagram incorporates a heat transfer fluid heater for preheating the fluid before entering the solar collector field. The system could also be designed without the Heat Transfer Fluid heater, and pump (P1) whose objective is to pump the Heat Transfer Fluid up to the collector field. The cold tank of the storage provides the cold Heat Transfer Fluid to the solar collector loop and receives the cold Heat Transfer Fluid after it has gone through the steam generator. Furthermore, the hot tank provides hot Heat Transfer Fluid to the steam generator and receives hot fluid from the collector loop. The hot tank may also provide Heat Transfer Fluid to the cold tank if the temperature of the fluid in the hot tank is lower than what is needed in order to produce steam, thus the need for the hot tank to cold tank pump (P5). This pump delivers cooled thermal oil from the hot tank to the cold tank where it can be pumped into the collector loop again to regain heat.

5. Estimation of Thermal Energy Output

The thermal energy produced by the power plant a year was 219 GWh with an efficiency of 35%, as shown in **Figure 8**. There are losses in energy due two reasons that are solar energy losses in the field and power block. The solar field losses can be shown in forms of optical losses in the solar collectors and other components such as receivers and piping; however, the losses due to power block can be represented in mechanical, and thermal losses that happen due to running supplementary equipment.

6. Economic Advantages of Solar EOR

Solar EOR can decrease the amount of gases by up to 80% that can be used for other applications such as electricity generation, desalination. The economic results of this project were studied on the basis of the thermal power produced. The cost of energy use was calculated using the annual project direct costs, including solar collectors, receivers and heat energy storage costs, as well as indirect project costs such as engineering and construction costs. The simulation results show that the actual cost of the proposed plan was 6 $/KW, and the contribution of each component of the plant in this total amount is illustrated in **Figure 9** [23]. Comparing this value with the basic cost of the concentrated solar Collectors, the value is approximate and is the lowest for the other collectors as in **Figure 10**. It can be noted that the total half-cost of Levelized Cost of Energy (LCOE) contributes to solar energy with the storage capacity of the thermal energy at the same cost ratio at a rate of 50% of the cost of the plant.

7. Environmental Benefits of Solar EOR

Solar EOR's steam generation process has zero emissions. Solar EOR helps to reduce the quantity of nitrogen oxides and carbon dioxides in the atmosphere. Solar EOR technology has significant environmental economic benefits unlike conventional technology. Also, in terms of the environment, SEOR can reduce the emissions of EOR to 0.1 g CO_2/MJ [24] [25].

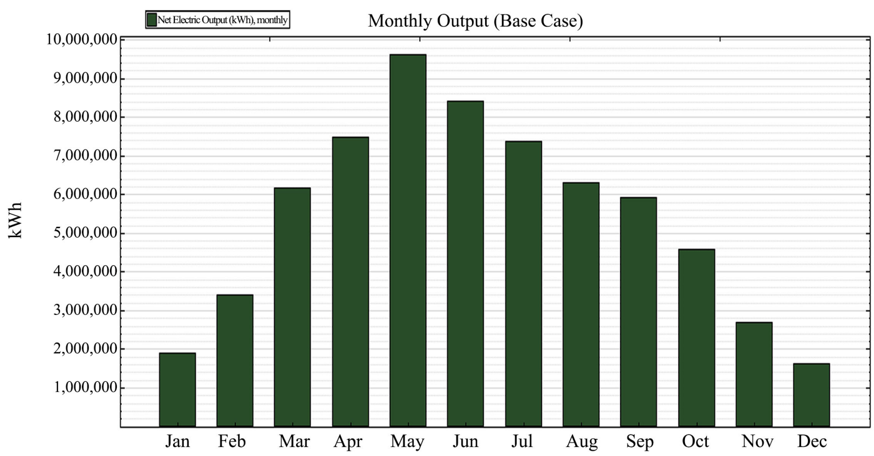

Figure 6. The average monthly of solar energy.

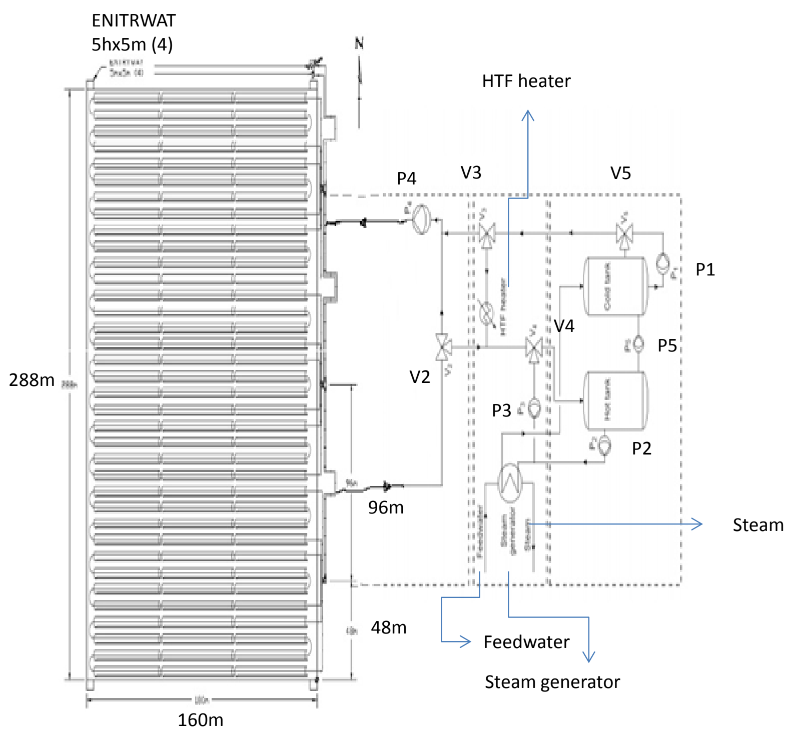

Figure 7. Layout and process flow diagram of the plant.

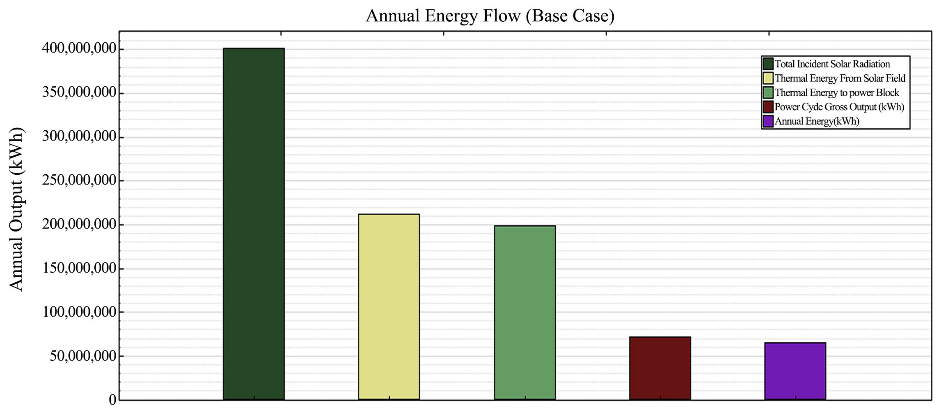

Figure 8. The amount of annual energy produced.

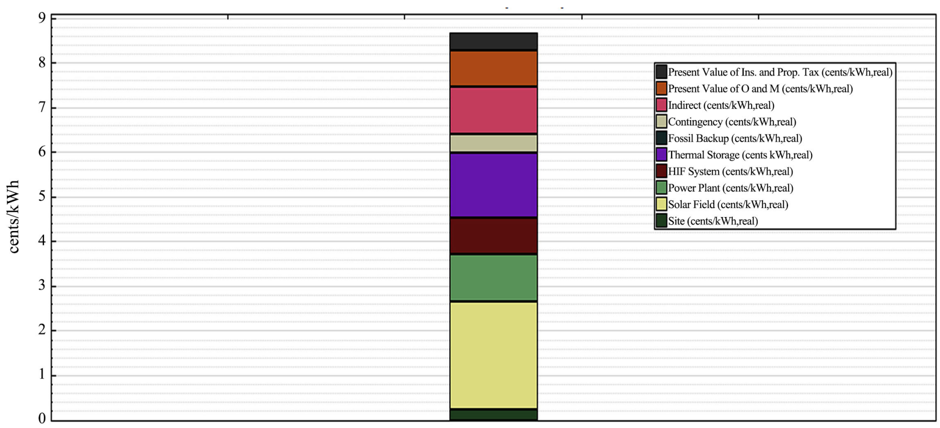

Figure 9. Total cost of the system.

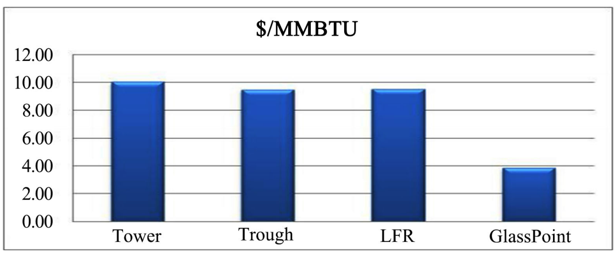

Figure 10. Comparing cost of the concentrated solar collectors [17].

8. Conclusion

In this study, the feasibility of integration of the upstream oil supply with renewable energy was presented. Solar energy was found to be the best source of renewable energy to be integrated into oil and gas industry. Hence, different types of solar energy technologies were studied. In addition, solar energy was evaluated for producing part of the energy requirement of the oil production process. Challenges in implementing such integration were outlined. A case study was carried out with the focus on Libya, to demonstrate the application of this study. From this study, it was observed that the integration of solar energy into oil and gas upstream operations was technically possible. Glass Point technology, supported by a good storage system, was a good example of solar integration operations for steam generation purposes. Significant amounts of CO_2 emissions, gas combustion and cooling water can be saved through this type of solar energy integration. Solar integration has financial advantages on the oil operations and can extend the life of the oil reservoir.

Recommendations

Since a number of challenges facing solar energy integration in Libya including technical, practical, economical, and institutional considerations, other studies could be carried out in future to address these challenges besides their solutions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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