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A Case Study of Solar Energy Application in Enhanced Oil Recovery

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Abstract Steam process is one of the most beneficial thermal enhanced oil recovery (TEOR) techniques, which is applied for heavy oil reservoirs to decrease viscosity, thus increasing the production rate. Traditionally, producing steam for TEOR requires consumption of massive amount of natural gas. Issaran Field is one of the largest heavy and extra heavy oil field in the world that was discovered in 1981 in Egyptian Eastern Desert. The required demand of steam for Issaran field is 25,000 bbl./day at 550 ˚F and 1000 psi. The objective of this study is to design a parabolic trough collectors (PTC) plant, which fulfils the required steam consumption need by Issaran heavy oil field. Results showed that solar energy has the ability to generate steam at the same quality as gas-fired system. PTC plant will produce almost 44.3% of total required steam. The cost of steam produced will be 0.658 $/steam bbl instead of 3 $ from gas-fired system. The cost of producing oil from the hybrid system is in average 19.8 $/bbl instead of 25 $/bbl from gas-fired system.

Keywords:• enhanced oil recovery • solar energy • parabolic trough collector • steam injection • heat transfer fluid

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1 Introduction

In 1981, one of the largest heavy oil field in the world was discovered. This field is called "Issaran Field". Issaran field is considered one of the few fractured carbonate heavy oil reservoirs in the world. It was discovered in the Egyptian Eastern Desert as shown in Figure (1). The location of Issaran Field is 290 km southeast of Cairo and 3 km inland from the western shore of Suez Gulf, and covering an area of 20,000 acres [1].

The initial oil in place in Issaran field is approximately 700 MM bbl, and its estimated reserve was approximately 500 MM bbl. This field has a viscosity range of 3,000-5,000 cp, and API gravity range of 90-120 API, which means that it contains heavy and extra heavy oil. Issaran field has five different formations as shown in Figure (2) created in Miocene age each one has its own unique characteristics, which are Ziet Formation (sandstone), Upper Dolomite formation, Lower Dolomite formation, Ghaeandal formation, and the deepest zone called Nukhul formation that has a depth 1,000 - 2,000 ft [1].

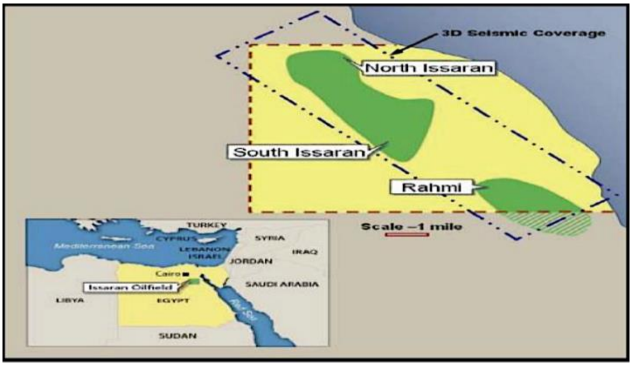

Figure 1. Issaran Field Location [1]

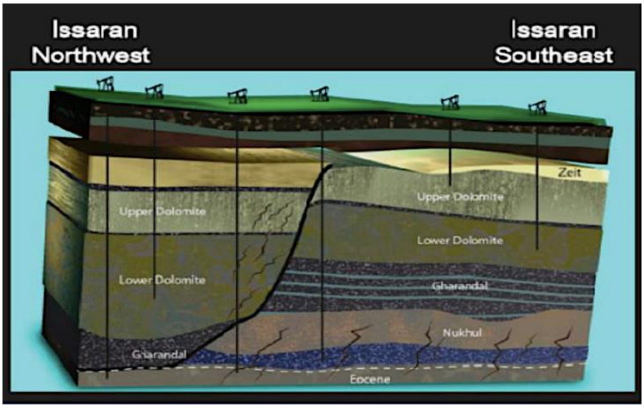

Figure 2. Issaran Field Formation [2]

From 1981 to 1987, the initial development of Issaran field was started with the drilling of 8 wells. The cumulative production up to 1998 was 0.7 MM bbl from 9 wells. In 1998, the heavy oil project was started, after creating a joint venture between General Petroleum Company GPC and Scimitar Production Egypt Ltd. The Initial oil in place at that time was 410 MM BBL, reserve 0.2 MM BBL, recovery factor less than 1%, the average production per well was below 30 BOPD, and the total field daily production was 170 STBOPD. In 1999, nine wells had been drilled in the field with a cumulative production of about 450 STBOPD. Generally, the primary recovery from such unconventional reservoirs cannot exceed 1%, with ultimate recovery less than 30%. Therefore, Issaran field did not command high priority, due to its low productivity and the low prices of its heavy and extra heavy crude oil [2].

In 2000, the Egyptian government made a great effort to develop Issaran field, due to the Global price increasing of crude oil. Consequently, the production rate reached 1,800 STBOPD from 5 new-drilled wells. In Jan 2006, the production rate was approximately 2,000 STBOPD, when EGPC's interest was acquired by Rally petroleum of Canada. Rally petroleum is a company with experience in the Canadian oil sands. Canadian oil sands have almost the same fluid properties of this heavy crude oil in Issaran field. Nukhul had been planned to develop with cold, due to its high fracture permeability. However, these high permeability layers soon created unwanted water channelling to the wellbore leading to high water cuts [3].

In August 2010, it was decided to apply the continuous steam flooding technique. The main objective of the continuous steam is to inject the steam in the up-dip of the producer wells to allow for gravity drainage, with the main withdrawal points being around the "magic fault". In 2013, 74 production wells were working to produce from south upper dolomite by continuously steam injecting in 21 injection wells. The steam flooding has worked well till the instantaneous steam oil ratio ISOR was equal to 10, which means that getting closer to uneconomical limits. ISOR is the ratio of the steam injected to the oil produced. ISOR is the key indicator of the economics of a steam drive project [3].

In 2014, a modified technique called "Steam Pulse Injection" SPI was tested in the upper dolomite south development to allow the project to continue at an economical rate. It is considered the first time using SPI technique in a dolomite formation. The main objective of using SPI technique was to minimize ISOR, and consequently minimizing the operating costs to an economical limit. After applying SPI technique, the overall ISOR was halved to an economical average of 5. Steam Pulse Injection was applied not only to minimize the operational costs, but also to get the benefits of the pressure release phenomenon that releases trapped oil from the matrix towards the fracture system and producing wells [3].

2 Solar Thermal Enhanced Oil Recovery Techniques

Solar thermal enhanced oil recovery is a modified technique of thermal enhanced oil recovery EOR. Solar TEOR is simply using solar energy to generate steam that will be injected in heavy oil reservoir instead of using gas-fired system. There are several categories of solar thermal technologies. Only two techniques are currently applied for solar EOR, which are; Enclosed Trough and Central Tower [4].

2.1 Enclosed Trough

Enclosed trough is simply a solar parabolic trough collector located inside a glasshouse. The purpose of this glasshouse is to protect and increase the efficiency of the solar parabolic trough collectors system. A single axis tracking system positions the collectors to track the sun and concentrate its light on the receiver pipes, also suspended from the glasshouse structure. One of the main advantage of this system is the ability of using reservoir water to generate the required amount of steam, without need of water treatment [5].

2.2 Central tower

Central tower has been initially designed for electrical generation. It is simply using large tracking mirrors called heliostats that will focus solar radiation in the boiler that filled with water located at the central tower to produce steam. The produced steam is then used either for steam purposes like in solar TEOR or for generating electricity [6].

3 Solar Thermal Enhanced Oil Recovery Projects; Case Studies

3.1 Coalinga solar thermal EOR project

In 2009, the cooperation between Chevron Corp. and Bright Source Energy began construction of a 29 MW solar thermal project at the Coalinga Oil Field in Fresno County, California. In October 2011, the project has been revealed. This project has spanned 100 acres and has 3,822 large tracking heliostats, each with two 10 ft by 7 ft mirrors mounted on a 6 ft steel pole concentrating the solar radiation on a 327 ft solar central tower. The Bright Source Energy was responsible to apply its solar technology, engineering and production, and construction services, while Chevron Corp. Ventures was the project operations management. Unfortunately, Chevron Corp. spent more than 28 million US dollar on this contract, and Bright Source Energy has lost at least 40 million US dollar on this project and disclosure will lose much more [6].

3.2 McKittrick Solar Thermal EOR projects

In February 2011, the first commercial solar TEOR project in the world has been installed by the cooperation between GlassPoint Solar and Berry Petroleum. The project was located on McKittrick Oil Field in McKittrick, California. This solar EOR project has been installed in less than six weeks, and spanned approximately 1 acre and produce around 1 million Btu per hour of solar heat [4, 6].

3.3 Solar Thermal EOR project in Oman

Shell Corporation has teamed with an investment fund from Oman to invest 53 million US dollar in Glasspoint Solar Inc. to fabricate an enclosed trough to generate the required demand of steam for TEOR process in Amal oilfield. This solar TEOR facility produces 50 metric tons of steam per day for injection, is a 7 MW installation. The use of renewable energy like solar power makes great economic sense, as the fuel cost associated with this EOR technology is practically zero. However, solar steam has zero CO_2 emission, instead of the steam that is produced due to natural gas burning [7, 8].

The main objective of this study, after finishing the literature review is to design a parabolic trough collectors (PTC) plant, which fulfils the required steam consumption need by Issaran heavy oil field.

4 Design, Results and Discussion

HTF is usually used in PTC systems that dealing with temperatures greater than 200 ºC, due to the high pressure that will be inside the receiver tubes and piping, if water is used. Therefore, it is required to use stronger joints and piping to withstand this high pressure. Actually, this will increase the PTC cost and thus the entire solar field. a mixture of water/ethylene glycol or pressurized liquid water is usually used For temperatures less than 200 ºC, because the required pressure to maintain fluid in liquid phase is moderate [4].

Parabolic trough collectors system has been designed as shown in Figure (3) to heat up HTF that is implemented in the system, which is BP Transcal N, and then used to transfer its heat to feedwater in heat exchanger to generate the required steam. The designing process started with identifying the demand required by Issaran Field. This process is followed by applying the mathematical calculations for designing this PTC system as illustrated and discussed in [10]. The optical and geometrical Parameters of the designed PTC are presented in Table (1).

The schematic diagram of the designed PTC is shown in figure (4).

The solar energy is varied in Issaran oil field due to the seasonal change as shown in Figure (5).

The heat gain by single PTC due to the change in solar radiation is represented in Table (2).

Table 1. Optical and Geometrical Parameters of PTC

Parameter	Value
Length (m)	9
Aperture width (m)	8.2
Focal Distance (m)	1.22
Aperture area (m^2)	73.629
Concentration ratio	137
Reflector reflectivity	0.89
Type of receiver	Red coated Copper
Glass cover	Transparent 4mm glass
Type of steel	not selected
Receiver outer diameter (m)	0.019
Receiver thickness (m)	0.003
Receiver inner diameter (m)	0.016
Receiver length (m)	9
Absorptivity	0.9
Emittance	0.023-.052
Glass transmissivity	0.95

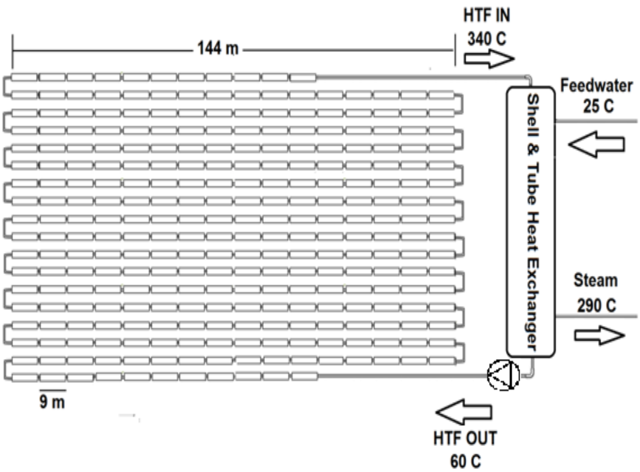

Figure 3. Schematic Diagram of Designed PTC

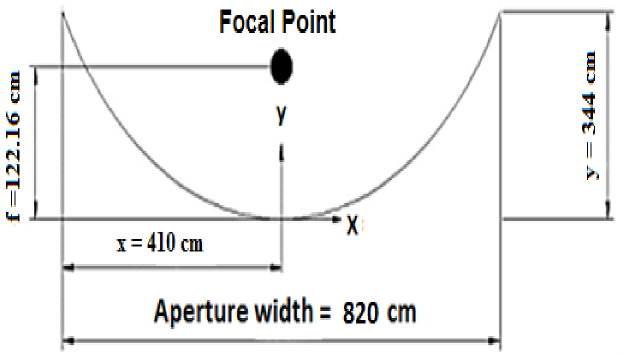

Figure 4. Schematic diagram of the designed PTC

Figure 5. Solar energy during the year

Table 2. Heat gain by single PTC during the year

Month	Q_u (W)
January	20531.92
February	23777.98
March	26901.57
April	27129.36
May	25777.05
June	25741.49
July	25735.51
August	27257.55
September	27439.75
October	24085.92
November	20068.1
December	18492.87

The amount of produced steam is mainly depend on the seasonal solar radiation, the peak is 12913 bbl/day in June and the average production is 11080 bbl/day as shown in Figure (6).

The cost of material used to design single parabolic trough collector is calculated as represented in Table (3).

The cost reduction after using solar is 34.6%, and its peak is 40.3% in June as represented in Table (4).

The cost of steam produced will be 0.658 $/steam bbl instead of 3 $ from gas-fired system. The total cost of producing 1 barrel of oil from the hybrid system is in average 19.8 $/bbl and its minimum cost is 18.95 $/bbl in June as presented in Table (5), where its cost conventionally was 25 $/bbl.

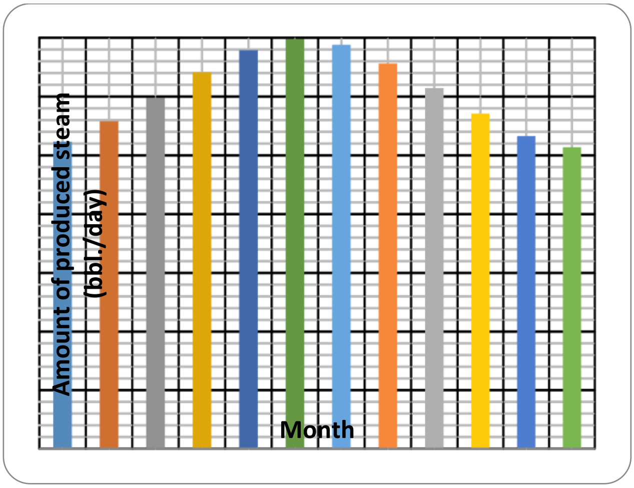

Figure 6. The amount of produced steam from PTC system (bbl./day)

Table 3. Material cost for single PTC

Item	Used material	Cost ($)
Trough support	Iron	200
reflector	Stainless steel with mirror finish	1600
Reflector chassis	Aluminium	4850
Tubing	Copper with D_o= 19mm D_i=16mm	58.33333
Bearing	4 bearing made in japan	5.555556
DC motor & circulating Pump	-	2000
Isolation	Layers of reflective material	200
Trough support manufacturing		33.33333
Arduino +wiring +sensors (additional)		22.22222
Total cost of single PTC ($)		8969.444

Table 4. Solar cost reduction

Month	Solar cost reduction (%)
January	29.4268
February	31.59531
March	34.08911
April	36.79976
May	39.13092
June	40.3236
July	39.72726
August	37.72138
September	35.11916
October	32.40851
November	30.02314
December	28.83045
Average	34.59962

Table 5. The cost of produced oil after using solar energy

Month	Cost of produced oil ($/Oil bbl)
January	20.58598056
February	20.26070278
March	19.88663333
April	19.48003611
May	19.1303625
June	18.95145972
July	19.04091111
August	19.34179306
September	19.73212639
October	20.13872361
November	20.49652917
December	20.67543194
Average	19.81005752

5 Conclusion

It was found that solar energy can generate the same quality of steam as natural gas for Issaran field. The amount of steam produced from designed Parabolic trough collectors system is mainly depend on the seasonal solar radiation, the peak of produced steam is 12913.19444 bbl/day in June and the average production is 11080.15046 bbl/day. The PTC system will produce an average of 44.3% of total required steam, and its peak production will be 55.8% in June. The cost of steam produced will be 0.658 $/steam bbl instead of 3 $ from gas-fired system. Actually, there is a significant reduction in the daily cost of steam after applying the solar energy in Issaran heavy oil field. The cost reduction is 25,949.7 $/day, and its peak is 30,242.7 $/day in June. The solar cost reduction is 34.6%, and its peak is 40.3% in June. The cost of producing oil from the hybrid system is 19.8 $/bbl as an average instead of 25 $/bbl from gas-fired system. The payback period of this project will be after 7 years. Using solar energy for producing steam could be a viable alternative to gas fired steam production for the oil industry.

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