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Market Potential of Solar Thermal Enhanced Oil Recovery-A Techno-Economic Model for Issaran Oil Field in Egypt

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Abstract. Solar thermal enhanced oil recovery (S-EOR) is an advanced technique of using concentrated solar power (CSP) technology to generate steam and recover oil from maturing oil reservoirs. The generated steam is injected at high pressure and temperature into the reservoir wells to facilitate oil production. There are three common methods of steam injection in enhanced oil recovery – continuous steam injection, cyclic steam stimulation (CSS) and steam assisted gravity drainage (SAGD). Conventionally, this steam is generated through natural gas (NG) fired boilers with associated greenhouse gas emissions. However, pilot projects in the USA (Coalinga, California) and Oman (Miraah, Amal) demonstrated the use of S-EOR to meet their steam requirements despite the intermittent nature of solar irradiation. Hence, conventional steam based EOR projects under the Sunbelt region can benefit from S-EOR with reduced operational expenditure (OPEX) and increased profitability in the long term, even with the initial investment required for solar equipment. S-EOR can be realized as an opportunity for countries not owning any natural gas resources to make them less energy dependent and less sensible to gas price fluctuations, and for countries owning natural gas resources to reduce their gas consumption and export it for a higher margin. In this study, firstly, the market potential of S-EOR was investigated worldwide by covering some of the major ongoing steam based EOR projects as well as future projects in pipeline. A multi-criteria analysis was performed to compare local conditions and requirements of all the oil fields based on a defined set of parameters. Secondly, a modelling approach for S-EOR was designed to identify cost reduction opportunities and optimum solar integration techniques, and the Issaran oil field in Egypt was selected for a case study to substantiate the approach. This modelling approach can be consulted to develop S-EOR projects for any steam flooding based oil fields. The model was developed for steam flooding requirements in Issaran oil field using DYESOPT, KTH's in-house tool for techno-economic modelling in CSP.

INTRODUCTION

Steam based thermal enhanced oil recovery (EOR) mainly involves three techniques – cyclic steam stimulation, continuous steam injection and steam assisted gravity drainage. Conventionally, the steam for thermal EOR is generated using NG fired boilers which incurs a running cost of using NG and dependency on NG price fluctuations. Additionally, these boilers also emit greenhouse gases in the atmosphere posing environmental issues. Considering the economic and environmental issues associated with conventional use of NG based boilers, there exists a strong potential to integrate renewable energy sources particularly CSP technology to generate steam. CSP offers an opportunity to produce steam without any emissions and despite its high investment cost, it has low operational cost which can outweigh the cost of running NG based boilers. CSP plants typically lasts for 30-40 years and therefore, oil fields under the sunbelt region can benefit from increased profitability in the long term. The steam requirements can be met using solar power thus savings tons of NG which can be used for other domestic purposes like electricity generation or can be exported to other countries for a high margin. There have been three pilot projects using CSP for thermal EOR – the Coalinga, California, USA (2011-14) based on CSP tower, the Kern county 21Z, California, USA (2011) based on parabolic trough and the Miraah, Amal, Oman (2012) based on parabolic trough.

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MARKET POTENTIAL OF S-EOR

Steam based thermal EOR covers approximately half of the world's EOR activities and therefore, studying an oil field for its suitability to adopt CSP for steam generation can result in significant reduction of NG consumption. Presently, no research consolidates the information of NG fired steam based oil fields and compares them at the level of a defined set of parameters to identify opportunities for S-EOR. The countries for market research were selected based on oil initially in place (OIIP) and newly discovered oil fields. These countries include USA, Canada, Brazil, Venezuela, Indonesia, Egypt, Oman, Trinidad and Netherlands. The parameters considered for market study of the oil fields included oil production, direct normal irradiation (DNI), steam requirements, NG price, NG availability (geopolitical stability, size of imports and exports), oil field location (fixed, floating, inside/outside a city), land topography, CSP penetration in the country and any political will to introduce renewable technologies.

In the United States, most of the steam injection projects are concentrated in California and the study conducted by NIPER [1] identified the Gulf Coast oil fields for potential steam flooding. According to EIA [2], the United States has enough NG to last about 84 years at current consumption rate. There are currently 26 CSP projects in the United States [3] which shows the huge penetration of CSP technology. Canada is the fifth largest producer of NG, and the fourth largest exporter of NG after Russia, Qatar and Norway [2]. SAGD is the most common method for EOR in Canada. Canada has currently only one CSP plant of 1 MW capacity but generates about half of its electricity through hydropower with significant contribution from wind power [3]. Brazil has four major basins with oil fields and has second largest NG reserves in South America. Renewable sources contribute 82.5% of Brazil's electricity production, with mainly hydropower and biomass, and there are no CSP plants [4]. Brazil imports NG primarily from Bolivia followed by Nigeria and Qatar to meet its demand. Venezuela's Orinoco heavy oil belt is expected to begin using EOR techniques, primarily SAGD and CSS in few years. The oil fields in the Bolivar Coast utilized steam flooding for about 50 years and are in their last phases of production. Venezuela is a net consumer of NG and around 35% of its NG production is consumed in oil recovery. Currently, there is no CSP plant in Venezuela and hydropower contributes around 64 % to power generation [2]. Indonesia's Duri oil field is the biggest steam flood project in the world. Indonesia is a major exporter of NG to Singapore and Malaysia. The NG exports are decreasing due to increasing domestic demand and therefore, S-EOR could be very useful in diverting the use of NG. Indonesia is planning to expand its hydropower and geothermal resources to at least 23% by 2025, and several new solar PV plants have been proposed by the government [2]. Egypt's Issaran oil field, situated in the Egyptian eastern desert uses steam flooding for oil production. Steam flooding started with CSS application in 2004 and later, it was replaced by steam drive method. Decreasing domestic NG production in Egypt has affected both its exports as well as electricity generation, which prompted local banks to fund solar energy projects for power production. Hence, based on the current situations, the Issaran oil field was selected to develop a techno-economic model of SEOR. Egypt is currently developing its second CSP plant in Kom Ombo and its government had announced large scale and roof top solar PV programs to generate electricity [5]. Oman has large use of EOR and Glasspoint, in partnership with Petroleum Development Oman, is building the S-EOR project called Miraah in Amal-West field. Due to increasing dependence on NG for electricity generation, Oman plans to end most of its LNG exports by 2024 [6]. Oman currently generates electricity primarily from NG and diesel, but it has planned to install one solar and two wind projects [2] by 2020. In Trinidad, Petrotin operates Cruse 'E' field as one of its most recent steam flood projects. Trinidad is the largest oil and NG producer in the Caribbean and world's sixth largest LNG exporter with primary exports to the United States [2]. As of 2015, 99% of the electricity is NG based and by 2020, the government plans to achieve 2.7% share of renewable electricity with higher potential for solar power compared to other renewable sources [7]. Netherlands' oldest oil field with thermal EOR is the Schoonebeek field whose production was restarted recently using gas fired combined heat-power plant to generate steam for SAGD and deliver surplus power to the national grid [8]. Netherlands is the second-largest producer and exporter of NG in Europe and produces 12% of its domestic power through renewables primarily from biomass, waste and wind [2].

TABLE 1. Parameters of oil fields with thermal EOR

Coalinga, California, USA [9]			Steam temperature	229	[^{0}C]
Start of steam injection	1962	[-]	Steam quality	80	[%]
Oil production rate	27,000	[BOPD]	Steam injection method	Steam drive	
Steam injection rate	0.6 - 1.4	[ktons/day]	DNI	2,222	[kWh/m^2/yr]
Steam pressure	406	[psi]	Topography	Flat, on land	

Cold Lake, Alberta, Canada [10]			Steam temperature	314	[^{0}C]
Start of steam injection	1978	[-]	Steam quality	80	[%]
Oil production rate	150,000	[BOPD]	Steam injection method	CSS	
Steam injection rate	262	[tons/day]	DNI	1,738	[kWh/m^2/yr]
Steam pressure	1500	[psi]	OIIP	20,000	[MMSTB]
Peace River, Alberta, Canada [11] [12]			Steam temperature	278	[^{0}C]
Start of steam injection	1973	[-]	Steam quality	95	[%]
Oil production rate	80,000	[BOPD]	Steam injection method	SAGD	
Steam injection rate	640	[tons/day]	DNI	1,586	[kWh/m^2/yr]
Steam pressure	915	[psi]	OIIP	20,000	[MMSTB]
Estreito, Brazil [13]			Steam temperature	219	[^{0}C]
Start of steam injection	1984	[-]	Steam quality	75 - 80	[%]
Oil production rate	28,000	[BOPD]	Steam injection method	CSS and steam drive	
Steam injection rate	9.6 - 22	[ktons/day]	DNI	1,413	[kWh/m^2/yr]
Steam pressure	333	[psi]	OIIP	725	[MMSTB]
Carmópolis, Brazil [14]			Steam temperature	179	[^{0}C]
Start of steam injection	1978	[-]	Steam quality	75 - 80	[%]
Oil production rate	18,100	[BOPD]	Steam injection method	Steam drive	
Steam injection rate (C-4 Zone)	1	[ktons/day]	DNI	1,588	[kWh/m^2/yr]
Steam pressure	129	[psi]	OIIP	1,591	[MMSTB]
Tia Juana, Bolivar Coast, Venezuela [15]			Steam temperature	252	[^{0}C]
Start of steam injection	1959	[-]	Steam quality	80	[%]
Oil production rate (M-6, del este)	20,500	[BOPD]	Steam injection method	CSS and steam drive	
Steam injection rate (M-6, del este)	6 - 8.5	[ktons/day]	DNI	891	[kWh/m^2/yr]
Steam pressure	500	[psi]	OIIP	6,015	[MMSTB]
Bachaquero, Bolivar Coast, Venezuela [16]			Steam temperature	307	[^{0}C]
Start of steam injection	1971	[-]	Steam quality	80	[%]
Oil production rate (Bachaquero-01)	40,000	[BOPD]	Steam injection method	CSS	
Steam injection rate	362	[tons/day]	DNI	887	[kWh/m^2/yr]
Steam pressure	1394	[psi]	OIIP	7,280	[MMSTB]
Duri, Indonesia [17]			Steam temperature	237	[^{0}C]
Oil production rate	236,000 - 285,000	[BOPD]	Steam quality	70	[%]
Steam injection rate	190 - 206	[ktons/day]	Steam injection method	Steam drive	
Steam pressure	475	[psi]	DNI	892	[kWh/m^2/yr]
Issaran, Egypt [18] [19]			Steam temperature	260	[^{0}C]
Start of steam injection (CSS)	2004	[-]	Steam quality	80	[%]
Oil production rate	5,000 - 6000	[BOPD]	Steam injection method	Steam drive (earlier CSS)	
Steam injection rate	317 - 476	[tons/day]	DNI	2,736	[kWh/m^2/yr]
Steam pressure	680	[psi]	OIIP	500	[MMSTB]
Amal-West, Oman [20]			Steam temperature	311	[^{0}C]
Start of steam injection	2007	[-]	Steam quality	80	[%]
Oil production rate	358	[BOPD]	Steam injection method	Steam drive	
Steam injection rate	7,500	[tons/day]	DNI	2,057	[kWh/m^2/yr]
Steam pressure	1,160	[psi]	OIIP	830	[MMSTB]

Cruse E, Trinidad [21]			Steam temperature	283	[^{0}C]
Start of steam injection	1996	[-]	Steam quality	80	[%]
Oil production rate	350	[BOPD]	Steam injection method	Steam drive	
Steam injection rate	317	[tons/day]	DNI	1,201	[kWh/m^2/yr]
Steam pressure	1,000	[psi]	OIIP	31.1	[MMSTB]
Schoonebeek, Netherlands [22]			Steam temperature	225	[^{0}C]
Start of steam injection	2008	[-]	Steam quality	80	[%]
Oil production rate	18,870	[BOPD]	Steam injection method	SAGD	
Steam injection rate	8 - 10	[ktons/day]	DNI	870	[kWh/m^2/yr]
Steam pressure	350	[psi]	OIIP	1,069	[MMSTB]

TECHNO-ECONOMIC MODELLING APPROACH FOR S-EOR

As indicated in the market research of oil field in Egypt, there exists a potential of S-EOR in the Issaran oil field which can divert the use of NG from consumption in EOR to exports or domestic power production. The current NG based continuous steam injection will be replaced with solar generated steam and the simulations on S-EOR have proved that there is no impact on the oil recovery by solar generated steam (compared to continuous steam injection), provided the cumulative amounts of steam injected during the same time-span are same [23]. In this research, a direct steam generation (DSG) plant using concentrating solar tower technology has been designed to meet the steam requirements for EOR in the Issaran oil field, Egypt. The model was developed using DYESOPT (Dynamic Energy Systems Optimizer), KTH's in-house tool for techno-economic modelling in CSP. The modelling approach and procedure created for S-EOR in DYESOPT can be used to design a solar tower DSG plant for any oil field. The analysis on DYESOPT needs location specific inputs (such as hourly meteorological data, economic indicators and NG prices), plant design parameters and cost functions at the component level. With these inputs, the power plant was designed at nominal (steady state) conditions and the design was used to run an annual performance simulation on TRNSYS whose results were used for techno-economic performance evaluation.

TABLE 2. Operating modes of the designed S-EOR plant for the Issaran oil field, Egypt

OMs	Description
OM1	Fresh and produced water are mixed and pumped to the receiver and steam is generated using heat from the solar field
OM2	The solar steam generated during the day is less than the daily steam needs and NG fired boiler supplements the steam
OM3	There is no solar steam generation and NG fired boiler meets the daily steam needs

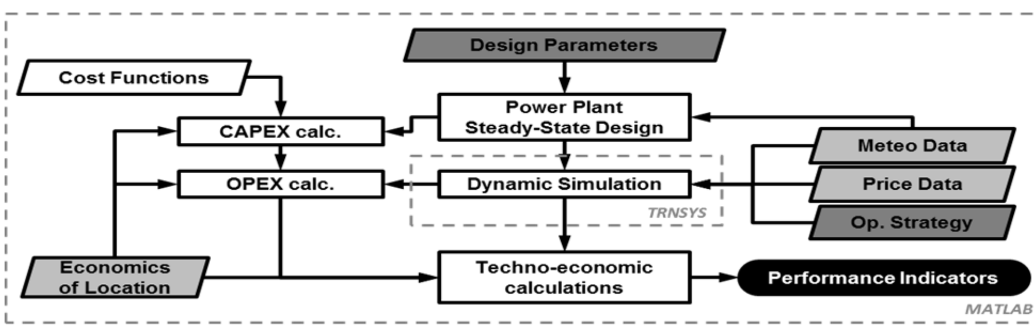

FIGURE 1. Modelling approach and calculation flow in DYESOPT

Input Data: Plant Design Parameters and Location Specific Information

As mentioned before, DYESOPT needs several inputs and Table 3 shows the relevant parameters and their values, which were used to create the model in DYESOPT. The solar multiple, tower height and receiver width were varied to obtain an optimal solution described in section 4. In this research, the meteorological data was obtained from meteonorm for the coordinates 28°45'N, 32°45'E with a time span of 1 hour. The baseline prices for domestic consumption and export of NG were found to be 3.4 \$/MMBtu and 4.9 \$/MMBtu respectively. A sensitivity analysis on the NG prices was performed to measure its impact on plant economics.

TABLE 3. Critical inputs for the S-EOR plant

Steam temperature	260	[^{0}C]	Solar multiple	0.3 : 2.3	[-]
Steam pressure	680	[psi]	Tower height	50 : 120	[m]
Steam quality	80	[%]	Receiver width	2 : 5	[m]
Steam injection rate	399	[tons/day]	Fraction of reused water	60	[%]
Domestic price of NG	3.39	[\$/MMBtu]	Export price of NG	4.94	[\$/MMBtu]

Steady State Design and Dynamic Modelling

As a first step, DYESOPT designs the plant at nominal (steady state) conditions using the input data mentioned in section 3.1. For this design, the steady state models of each component were implemented and the equations for the solar field were extracted from [24]. This allowed the sizing of each component which was used in dynamic modelling on TRNSYS simulation studio. In TRNSYS, the solar field was modelled using STEC type 394 which takes an efficiency matrix as an input which maps the solar position to overall heliostat field efficiency. STEC type 390 was used for pumping fresh and produced water via enthalpy mixer, STEC type 330. A user made component was created as a receiver which calculates the amount of steam which can be generated using solar field power as an input and accordingly, sends a signal to the pumps to pump the required water flow rate. The feedback loop from receiver to the pump saves parasitic electricity consumption which reduces OPEX. Once TRNSYS model was established, an optimization process was used by varying solar multiple, tower height and receiver width.

Cost Functions and Economic Performance Indicators

To measure the economic performance of the S-EOR plant, levelized cost of steam (LCOS) and internal rate of return (IRR) were considered to be important performance indicators. In this research and specific to S-EOR application, LCOS is defined as the cost incurred during the lifetime of the project divided by the total amount of solar steam generated expressed as \$/(ton of solar steam). For CAPEX, the costs were derived based on the models in [25] using reliability functions to scale-up costs based on reference costs for Egypt [26] and respective labor and material cost multipliers to achieve sensible costs estimations. For some of the costs estimations, reference costs from [27] were used for the United States and adjusted for Egypt with labor wage ratio and GDP ratio. The annual OPEX was also derived based on the models in [25] and capped at within one percent of the CAPEX based on [28]. The LCOS was calculated using (1) as a function of CAPEX, annual OPEX and amount of solar steam generated throughout the year. The factor α, also called as capital return factor, was calculated using (2) where *i* stands for the real interest rate (assumed 10 %), *n* for project lifetime (assumed 30 years) and k_{ins} for the insurance rate (assumed 1%). Another indicator called levelized cost of fuel (LCOF) was defined as LCOS divided by the total thermal energy consumed (in MMBtu) to generate that annual solar steam, expresses as \$/MMBtu.

$$LCOS = [\alpha \cdot CAPEX + OPEX] \cdot \left(Steam_{solar}\right)^{-1} \quad (1)$$

$$\alpha = \left[i \cdot (1+i)^n\right] \cdot \left[(1+i)^n - 1\right]^{-1} + k_{ins} \quad (2)$$

The revenues or savings generated by avoiding NG burn due to solar steam generation, $\lambda_{NGsavings}$ was calculated using (3) as a function of annually avoided NG burn rate $NG_{avoided}$, domestic consumption price of NG and export price of NG. The savings calculation assumes that all the NG which is saved from being consumed in EOR is exported. The amount of CO_2 emissions reduced from avoiding NG consumption was calculated based on boiler emission rate from [29].

$$\lambda_{NGsavings} = [NG_{avoided}] \cdot \left(price_{domestic}^{NG} + price_{export}^{NG}\right) \quad (3)$$

The net present value (NPV) was calculated using (4) as a function of CAPEX, annual OPEX, discount rate IRR, years of plant construction n_{con}, the years of plant operation n_{op}, the annual revenue from NG based savings $\lambda_{NGsavings}$, the years of plant decommissioning n_{dec} and the decommissioning costs C_{dec}, based on the cost models [25] and decommissioning values from [24]. Finally, the other important performance indicator IRR, was calculated using (4) as the discount rate at which NPV of all the cash flows equal to zero at the end of the project lifetime.

$$NPV = -\sum_{t=0}^{n_{con}-1} \frac{CAPEX}{n_{con}(1+IRR)^t} + \sum_{t=n_{con}}^{n_{con}+n_{op}-1} \frac{\lambda_{NGsavings} - OPEX}{(1+IRR)^t} - \sum_{t=n_{con}+n_{op}}^{n_{con}+n_{op}+n_{dec}-1} \frac{C_{dec}}{n_{dec}(1+IRR)^t} = 0 \quad (4)$$

RESULTS FROM TECHNO-ECONOMIC MODELLING OF S-EOR

This S-EOR plant is a hybrid of solar based steam and NG based boiler steam, and therefore appropriate share of solar was reached by optimizing two objective functions - maximizing IRR and minimizing LCOS, and minimizing CO_2 emissions and minimizing LCOS. Figure 2 shows the results from the multi-objective optimization and it was found that an optimum point between the two objective functions can be reached with LCOS of 23 \$/ton, IRR of 18% and CO_2 reduction of 26,000 tons/yr. However, as there is no carbon tax in Egypt (as of July 2016), the priority was given to maximizing IRR with minimum LCOS. Table 4 summarizes the S-EOR plant design and performance indicators. The economics of this S-EOR plant shows that the LCOS is 17.3 \$/ton compared to 17 \$/ton of Glasspoint's research on parabolic-trough based S-EOR plant [30]. The LCOF is 8.0 \$/MMBtu and it is very close to the Asian LNG spot price of 7.5 \$/MMBtu as of February 2015 [31]. This LCOF shows that the cost of using solar thermal power as a fuel is \$ 1.2 higher than using the same amount of thermal power from NG. The IRR was calculated to be 27.4% using (4) with a payback period of 6 years, which can be significantly attractive for the investors. In this research, the tax savings due to reduction in CO_2 emissions was not considered and if it is considered conservatively as 10 \$/ton of CO_2, then the economic performance of the S-EOR plant will improve and the IRR will increase from 27.4% to 29.4%.

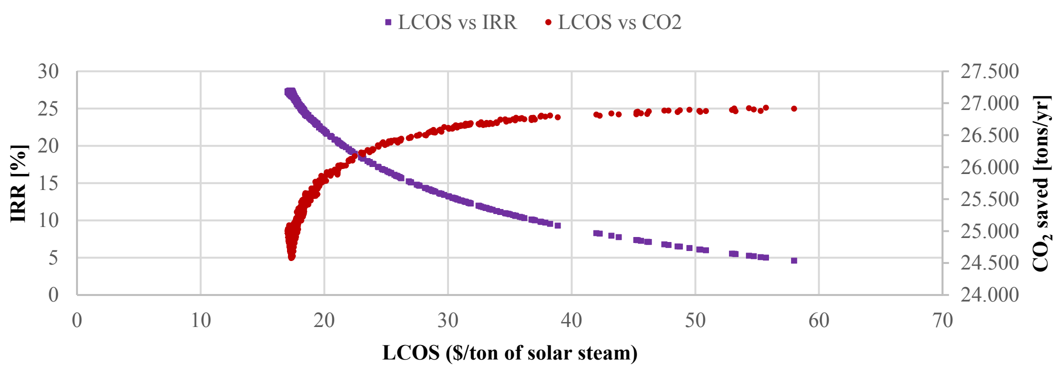

FIGURE 2. Optimization results for the S-EOR plant

TABLE 4. S-EOR plant design and performance indicators

CASH FLOWS			FIELD DESIGN		
CAPEX	10.8	[milUSD/yr]	Number of heliostats	1,628	[-]
OPEX	0.1	[milUSD/yr]	Total land area	74,691	[m^2]
ECONOMIC INDICATORS			STEAM GENERATION		
LCOS	17.3	[\$/ton steam]	Annual solar steam	155.8	[ktons/yr]
LCOF	8.0	[\$/MMBtu]	Annual NG boiler steam	12.9	[ktons/yr]
IRR	27.4	[%]	Annual solar steam spillage	23.0	[ktons/yr]
NPV	17.0	[milUSD]	Annual CO_2 emissions saved	24,629	[tons/yr]

As the NG price is one of the main drivers of savings from avoided NG burn, a sensitivity analysis of NG price was also performed as shown in Figure 3. Two different cases were considered where case (a) represented a domestic consumption price of 3.39 \$/MMBtu and case (b) represented when the domestic consumption of NG is free to the operating stakeholder. In case (a), it can be seen that as export price increases, the payback period reduces from 8.4 to 5.1 years while IRR increases from 15.9% to 32.6%. While in case (b), as export price increases, the payback period reduces from 14.7 to 6.7 years while IRR increases from 4.2% to 22.4%. It was assumed that all the NG saved from being consumed in boiler is exported, and this assumption can be reinforced with two improvements. First, as Egypt exports NG to different countries, the export prices for each country can be different.

Second, if the NG is not exported then it can be consumed in domestic power production to tackle Egyptian power crisis and therefore, revenues generated by selling NG to power producers can be considered in economic calculations.

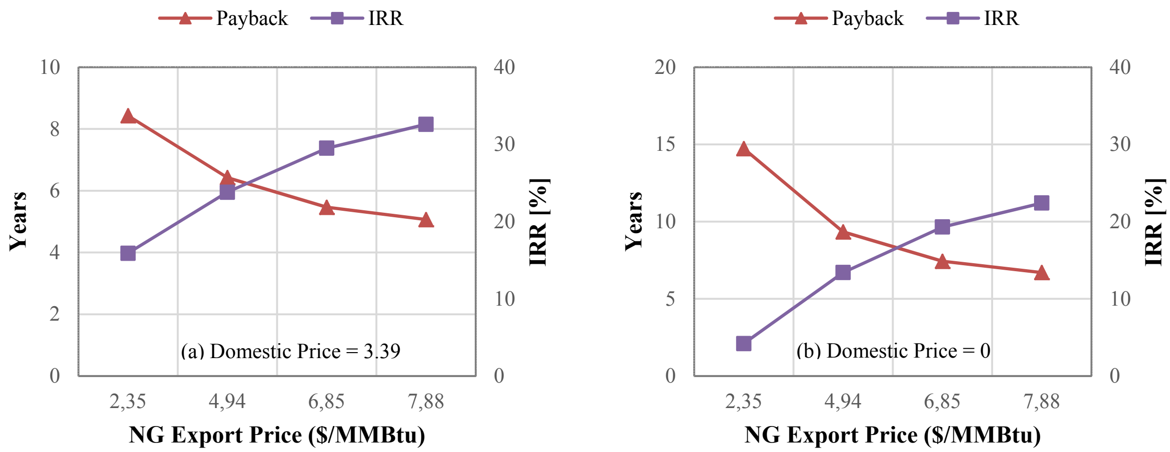

FIGURE 3. Sensitivity of NG prices on payback and IRR (a) Domestic Price = 3.39 $/MMBtu (b) Domestic Price = 0 $/MMBtu

CONCLUSION

This research provides a comprehensive overview on existing oil fields using steam flooding methods for oil recovery as well as a techno-economic modelling approach to design a solar tower based DSG plant for steam generation. The market research was conducted for twelve major oil fields in nine different countries covering several aspects of the market which could impact the attractiveness of CSP for S-EOR. This research consolidated the information of each oil field characterized by different parameters which helped in realizing (and comparing) the size and EOR activity at any oil field. Several external factors like governmental targets of renewable energy, exports and imports of oil and NG were also considered to provide a holistic view of the S-EOR market in any country. Based on the outcome of market research, the Issaran oil field in Egypt was selected to develop a techno-economic model of S-EOR using DYESOPT.

Considering the steam requirements at the Issaran oil field, a solar field was first designed at a steady state whose results were subsequently used to perform a dynamic simulation for the entire year on TRNSYS. Using the developed model, a multi-objective optimization was performed to maximize IRR and minimize LCOS. Considering the domestic and export prices of NG in Egypt, a financial analysis was performed to calculate the economic indicators of the S-EOR plant. The LCOS was found to be 17.3 $/ton of solar steam which is comparable to estimations by Glasspoint for their S-EOR plant. The payback period and IRR were found to be 6 years and 27.4% respectively, which can be very attractive for an investor. Moreover, the S-EOR plant has the potential to save 24.6 ktons/yr of CO_2 which proves that CSP can help the oil industry in reducing their emissions and save money with carbon tax, if applicable in the country. Finally, a sensitivity analysis of NG prices was performed to show how NG prices can impact the economic feasibility of EOR activities.

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REFERENCES

1. D.K. Olsen, W.I. Johnson and E.B. Ramzel, *Feasibility Study of Heavy Oil Recovery in the Lower 48 States*

(DOE Report NIPER-521, 1991).
2. Market analysis on EIA, http://www.eia.gov/beta/international/
3. H.X. Nguyen, W. Bae, D.H. Nguyen, X.V. Tran and D.Q. Ta, *Successful application of discontinuous SAGD technique to maximize oil recovery in Alberta's oil sands* (SPE 157866, 2012).
4. M.M. Cabré, G. Kieffer, A.L. Peña, A. Khalid and R. Ferroukhi, *Renewable energy policy brief Brazil* (IRENA, June 2015).
5. MENA solar outlook (Middle East Solar Industry Association, 2015), p.p.7.
6. Solar enhanced oil recovery-an in-country value assessment for Oman (EY, January 2014).
7. Framework for development of a renewable energy policy for Trinidad and Tobago (Ministry of Energy and Energy Affairs, January 2011).
8. F. Jelgersma, *Redevelopment of the abandoned Dutch onshore Schoonebeek oilfield with gravity assisted steam flooding* (IPTC 11700, 2007).
9. E.J. Hanzlik and D.S. Mims, *Forty years of steam injection in California – The evolution of heat management* (SPE 84848 2003).
10. S.D. Stark, *Cold lake commercialization of the liquid addition to steam for enhanced recovery (LASER) process* (IPTC 16795, 2013).
11. D. Vannaxay, F. Wasden and B. Howell, *Carmon Creek thermal field development project* (SPE-170879-MS, 2014).
12. P.F. Koci and J.G. Mohiddin, *Peace river Carmon Creek project-optimization of cyclic steam stimulation through experimental design* (SPE 109826, 2007).
13. R.F. Mezzomo, T.V. Dutra Jr., D.N. Miranda-Filho, A.L. Paula and D.F.S. Cursino, *Heavy oil recovery in Potiguar basin, Brazil: steamflooding from field pilot testing to commercial application* (SPE 71063, 2001).
14. R.F. Mezzomo, J.M. Luvizotto and C.L. Palagi, *Improved oil recovery in Carmópolis field: R&D and field implementations* (SPE 59280, 2000).
15. G.V. Riveros and H. Barrios, *Steam injection experiences in heavy and extra-heavy oil fields, Venezuela* (SPE 150283, 2011).
16. M.A. Escobar, C.A. Valera and R.E. Pérez, *A large heavy oil reservoir in lake Maracaibo basin: cyclic steam injection experiences* (SPE 37551, 1997).
17. J.C. Pearce and E.A. Megginson, *Current status of the Duri steamflood project Sumatra, Indonesia* (SPE 21527, 1991).
18. G.S. Basta, S.K. Korany, W.T. Kortam and S. Shaker, *Experiences of conversion from cyclic steam strategy to continuous steam strategy in Issaran Egypt field* (SPE-179773-MS, 2016).
19. T. Shaheen, W. Hassan, I. Siddiqqi and S. Kamal, *World's first combination of acid & steam provides a new dimension to heavy oil enhanced oil recovery* (SPE 154293, 2012).
20. S.A. Rice, *Steam-soak performance in south Oman* (SPE Reservoir Engineering, Nov 1991).
21. V. Ramlal, *Enhanced oil recovery by steamflooding in a recent steamflood project, Cruse 'E' field, Trinidad* (SPE 89411, 2004).
22. F. Jelgersma, *Redevelopment of the abandoned Dutch onshore Schoonebeek oilfield with gravity assisted steam flooding* (IPTC 11700, 2007).
23. A.P.G. van Heel, J.N.M. van Wunnik, S. Bentouati and R. Terres, *The impact of daily and seasonal cycles in solar-generated steam on oil recovery* (SPE 129225, 2010).
24. J. Spelling, "Hybrid Solar Gas Turbine Power Plants – A Thermoeconomic Analysis", Doctoral Thesis, KTH, 2013
25. C. Turchi and G. Heath, *Molten Salt Power Tower Cost Model for the System Advisor Model* (NREL/TP-5500-57625, 2013).
26. Local manufacturing potential for solar technology components in Egypt, World Bank Group (MENA energy series, July 2015).
27. CSP Solar Tower Report 2014: Cost, Performance and Thermal Storage, Technical Report, FC Business Intelligence (CSP Today, 2013).
28. R. Hosseini, M. Soltani and G. Valizadeh, *Technical and economic assessment of the integrated solar combined cycle power plants in Iran* (Renewable Energy 30, 2005), pp. 1541-1555.
29. Boiler selection considerations, CleaverBrooks, pp. 13.
30. M. Chaar, M. Venetos, J. Dargin and D. Palmer, *Economics of steam generation for thermal EOR* (SPE-172004-MS, 2014).
31. Global energy market outlook 2014/15 (BG group, 2014).