<u>**Integrating Renewable Energy Resources Within the Oil Industry**</u>

Concentrated Solar Power (CSP) & Enhanced Oil Recovery (EOR)

Introduction

Over the last decade there has been a substantial increase in awareness regarding the potential damage to the environment and future availability of the most valuable energy source of today, crude oil. This has caused many major oil companies to develop departments, and several companies to be founded with the sole intention of effectively harnessing renewable energy, the worlds most promising replacement of crude oil as a cleaner effective energy source.

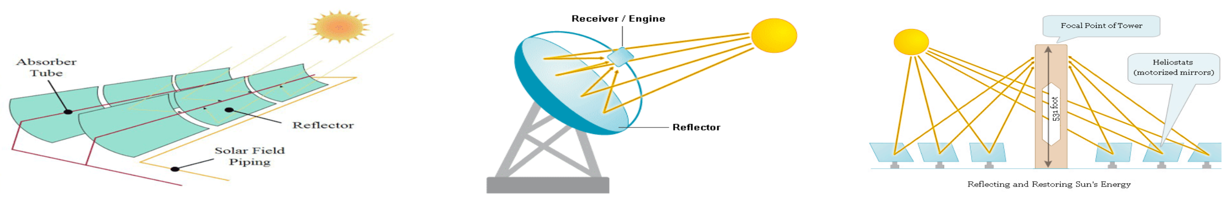
While the ability of several types of renewable energy (solar, wind, wave) to fully replace the burning of fossil fuels lies far into the future, there have been new focuses for the application of renewables involving not the replacement of the crude oil industry, but integration within to enhance the recovery of fossil fuels in a cleaner and effective manor. A revolutionary example of this is Concentrated Solar Power (CSP).

Concentrated Solar Power

CSP uses a series of mirrors to focus sunlight onto a heat conducting element, generating large quantities of high temperature heat that can be stored and used for the generation of electricity. An example covered thoroughly in this report is the superheating of water from mirror focused sunlight to produce large volumes of steam, which can be utilised in steam turbines as a power source. The CSP method differs from original solar powered technology (Photovoltaics) as is does not directly convert sunlight into electricity from the solar panels and can only operate in clear sky/sun-rich environments[1].

There are currently 3 primary designs used for CSP technology: Solar tower, parabolic trough and parabolic dish. The solar tower design has large individual sun-tracking mirrors surrounding and focusing on a receiver based at the top of a central tower, the heat produced is then transferred through a chosen media (water) for power generation (steam formation). The parabolic trough system uses trough shaped mirrors that focus sunlight onto receiver tubes containing oil or a similar fluid. This heats the oil to temperatures of around 400 degrees Celsius that is used to produce the necessary steam[2]. The parabolic dish design is not too dissimilar in concept with the solar tower aspect, using a dish shaped mirror to focus sunlight onto a small receiver superheating water to create steam as a power source.

Figures 1-3. Parabolic trough, dish and central tower CSP designs.



1 http://www.guardian.co.uk/environment/2009/may/26/solarpower-renewableenergy
2 http://www.greenpeace.org/raw/content/international/press/reports/Concentrated-Solar-Thermal-Power.pdf

The oil industry is under constant pressure to reduce the environmental harm caused by its processes of petroleum exploitation, from which new environmentally and cost beneficial methods are largely sought after. With the advancements CSP has brought to generating large volumes of superheated steam, there has been great interest in integrating this clean technology into the enhanced recovery of heavy oil from mature or complex fields, specifically using the thermal EOR (Enhanced Oil Recovery) method.

Enhanced Oil Recovery

The life cycle of an oil field can span for many decades depending on its complexity and size, and throughout this time many properties in the subsurface fluid and rock formation of the reservoir can drastically change, such as: Formation/fluid pressure (energy), oil gravity, permeability/porosity and oil viscosity. With these changes comes considerable alterations in the development strategy for the oil field, which tends to be broken into 3 stages: Primary, secondary and tertiary recovery.

Primary recovery occurs earlier in a field's life where oil is driven to production simply through pressure changes with the formation, fluid and production well causing the expansion of gas in oil solution, forcing the oil to the producing well. Secondary recovery processes are required when a reservoir becomes low in energy, where considerable oil (usually lighter in gravity) has been produced without fluid replacement in the reservoir leaving a low pressure that cannot naturally drive oil towards production. In these cases water flooding or gas injection (immiscible with oil) are techniques implemented through injection wells to increase pressure and displace hydrocarbons to production.

Tertiary recovery, also known as enhanced oil recovery (EOR) is commonly used in mature fields where secondary techniques such as water flooding no longer produce economically viable quantities of oil and start to exploit large quantities of the injected water. EOR methods inject specific fluids into the subsurface which can be highly viscous to improve hydrocarbon sweep efficiency, or can alter the properties of the oil and even the rock in some cases (wettability in carbonate reservoirs) to improve the flow of oil and increase production. The type of fluid injected largely depends on the characteristics of the oil (API gravity) and rock itself. The most renowned EOR methods used to improve oil recovery factors in fields worldwide are: Thermal injection (steam/fire flooding), miscible gas injection (CO2) and polymer injection.

EOR methods have responsibility for the largest oil recovery out of the 3 stages. After primary and secondary recovery the average reservoir still contains around 70% of its original oil in place[3], meaning EOR methods can sometimes extract just over half the total original reserves in place. EOR methods are extremely costly and the decision to push forward with tertiary recovery largely depends on the economic climate (oil price), which has been the main factor in the past why many large oil companies have decided to freeze production on fields rather than go forwards with EOR. However, over the last few years climates have enabled many companies to continue production on mature fields to exploit the large portion of remaining reserves. This can be seen from the global market change

3 *A Niche for Enhanced Oil Recovery in the 1990s (1992):* Larry W. Lake*, Raymond L. Schmidt, Paul B. Venuto*

from 2005 to 2009, where for barrels of crude oil EOR has been estimated to have risen from $3.1 billion (2005) to $62.5 billion (2009), highlighting the recent feasibility for many companies to perform EOR[4]. With increased government investment these figures are only expected to increase further over the next few years.

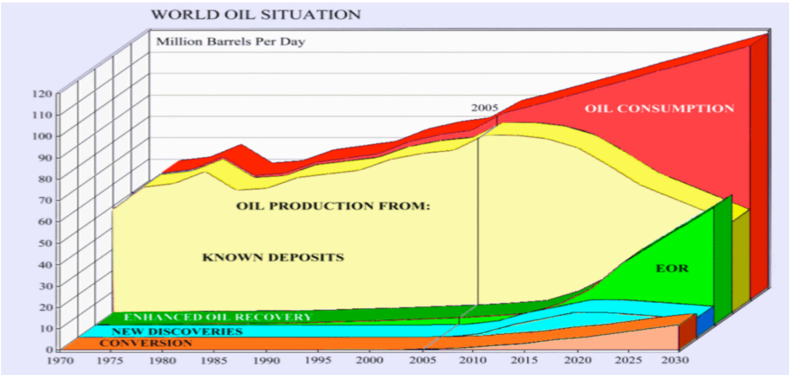


Figure 4. Graph to show present and future Oil production, consumption and EOR production rates.

Thermal EOR

Thermal recovery techniques are the most understood and technologically advanced methods of EOR in the industry today, controlling approximately half of the total enhanced oil recovery worldwide[5]. Thermal methods are commonly used when dealing with heavy viscous oils with API gravity less than 20 degrees and viscosities between 100-10000 centipoise, resulting in a very low mobility fluid that is difficult to produce. Thermal injection supply's heat down well into the reservoir, which increases the oil temperature causing partial vaporisation or expansion of the fluid (oil) leading to a reduction in its viscosity, therefore improving its ability to flow towards production.

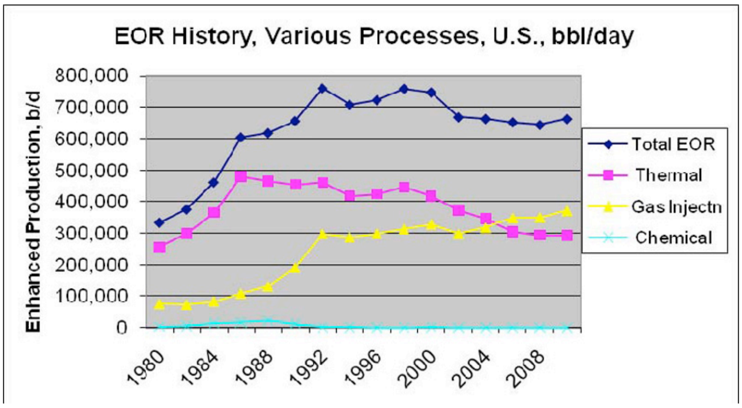


Figure 5. Graph showing Bopd through different EOR methods.

There are several thermal techniques employed to increase the mobility of heavy viscous oil in the subsurface: Cyclic steam stimulation, continuous steam injection, steam assisted

4 http://www.senergyworld.com/media-centre/newsletter/update-in-brief/the-challenges-and-opportunities-for-enhanced-oil-recovery-(eor)

5 http://www.slb.com/~/media/Files/resources/oilfield_review/ors92/0192/p55_61.ashx

gravity drainage and in-situ combustion. The technique chosen depends largely on the subsurface geology and formation of the reservoir.

Cyclic steam stimulation (CSS) uses a single well to inject superheated steam into a reservoir for short term periods (1 month), the well is then shut in for several days to allow the heating of oil and some steam to soak into oil solution reducing its viscosity. The single well originally used to inject is converted into a producing well which is reopened allowing the higher mobility oil to be exploited. This process can yield between 10-40% recovery of the oil in place and is repeated every time oil production rates for the reservoir drop to an uneconomical level[6].

Continuous steam injection unlike CSS injects a constant flow of superheated steam in to the reservoir using two wells, one producer and one injector. Recovery factors from this method can range from 50-60%[7], higher than its alternative CSS due to oil never cooling and decreasing in mobility like in the later stages of CSS production. However due to the constant flow of steam this can sometimes lead to a large excess of steam in the subsurface, which can cause substantial heat losses leading to an inefficient process.

Steam assisted gravity drainage (SAGD) is a technique commonly used for very heavy subsurface oils like bitumen[8]. Two horizontal wells (one producer below, one injector on top) are placed parallel into a reservoir and steam is injected forming a chamber at the top of a formation. Once it comes into contact with the oil, the oil viscosity is reduced allowing it to migrate downwards with gravity as a driving force to the producing well. For this technique to be successful careful consideration into the quality of vertical permeability in the area is needed.

The final significant technique of thermal recovery is in-situ combustion (fire flooding), in which oxygen or air is injected down well into the reservoir and ignited along with a portion of the oil in place, reaching temperatures of 450-600 degrees Celsius[9]. This method can greatly increase the mobility of oil in the zone through decreased viscosity by heating and the cracking of some longer chained hydrocarbons into smaller chains. Theoretically in-situ combustion is more efficient than any of the above steam processes due to its much lower level of heat loss in the process. However capital costs for this method are much higher, and it is far more complex to complete with many unknowns regarding the exposure of different subsurface environments to such high temperatures, with problems like rock cement failure and corrosion of the wells from oxygen and moisture. These issues have made this method very rare within the industry.

Thermal EOR has several challenges that can hinder its availability to oil companies when producing from mature fields, predominantly falling in the economic and environmental categories. Thermal injection techniques such as variable steam flooding is usually undertaken on the larger oil fields which are several kilometres in width, which inevitably

6 *Oil & Gas Science and Technology* – *Rev. IFP*, Vol. 63 (2008), No. 1, pp. 9-19, Enhanced oil recovery: An Overview
7 http://www.firp.ula.ve/archivos/cuadernos/08_OGST_Thomas_EOR.pdf
8 *Oil & Gas Science and Technology* – *Rev. IFP*, Vol. 63 (2008), No. 1, pp. 9-19, Enhanced oil recovery: An Overview
9 http://www.firp.ula.ve/archivos/cuadernos/08_OGST_Thomas_EOR.pdf

creates very large capital costs from multiple injection wells and expensive facilities with steam generators to continue development.

Environmental issues also pose large problems for companies performing thermal EOR on their oil fields, as increasing scrutiny on surface space consumption for fields makes limited area for steam generators on top of production facilities and flow lines. The steam generators needed for the thermal techniques also burn fuels that emit greenhouse gases such as CO2 into the atmosphere.

These economical and environmental issues in performing thermal EOR is what has led to many extensive areas of research for improvement, namely so the integration of renewable energy technology such as concentrated solar power into thermal EOR projects.

Improving the overall efficiency of thermal EOR with integration of CSP

The main interest for CSP in the thermal EOR sector of the oil industry is its ability to generate large quantities of steam in an economically and environmentally beneficial way. By using focused sunlight as a high temperature heat source CSP technology does not require the burning of natural gases and other fuels to produce steam, largely preventing the emission of greenhouse gases in the steam generation process. By not burning these fuels for steam you are also freeing up a valuable resource which some country's lack, such as natural gas, which can be used for many other purposes of profit generation elsewhere.

Overall costs for the CSP technology, specifically the parabolic trough design (the most commercially proven for operating[10]) have also been proven lower than the conventional steam generators used for thermal EOR today. Although capital costs of the CSP technology may be larger, the overall operating costs are much less than the burning of fuels to generate steam and this shows over the long time period EOR is implemented in a field. These lower costs can also be seen in theory with regards to the end of an oil producing project, the decommissioning of an oil field. As material demands for CSP techniques are much lower, safer and more cost effective than the original steam generation technology, it has the potential to simplify closing a project which is usually very costly and complex.

The clear advantages CSP can bring into the thermal EOR market lead to the first ever industry development of the concept by a pioneering U.S renewable energy organisation, GlassPoint. In early 2011 they introduced the first commercial solar powered thermal EOR project in Kern County, California, a mature field undergoing superheated steam injection to extend its producing life. Once changing the method of steam generation from burning fuels and natural gases to CSP, GlassPoint stated that steam was being produced at lower costs with the ability still to deliver up to 80% of the total annual thermal EOR project needs[11].

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10 http://www.greenpeace.org/raw/content/international/press/reports/Concentrated-Solar-Thermal-Power.pdf
11 http://www.energymatters.com.au/index.php?main_page=news_article&article_id=1369

Cost of energy produced/ million BTU	Energy source
$3-4	CSP
$4-4.50	Natural gas burning (US)
$5.25	Natural gas (future*)

Table 1. Shows the costs of producing energy from different techniques. GlassPoint's Kern County development produces approximately 1 million BTU's per hour[11].* Barclays

Due to the success of CSP thermal EOR in California, in early August 2011 GlassPoint were awarded there second contract by Petroleum Development Oman (PDO) to build the first CSP thermal oil recovery project in the Middle East. The Middle East is host to some of the biggest oil fields in the world, many of which are extremely mature with most of the "easy oil" exploited, making the concept of EOR rapidly become a very large part to their future production plans. A key example of just a small fraction of the potential market for EOR methods such as thermal is in Saudi Arabia, the worlds largest crude oil exporter, expect to be producing more than 1 million barrels of heavy oil per day (Bopd) from EOR by the year 2030[12].

While there are many promising advantages to CSP for use in thermal EOR, but the technology also faces several challenges that hinder its transition into the number one choice of steam generation for enhanced oil recovery projects.

As discussed, concentrated solar power technology requires clear skies and an abundance of direct sunlight to generate large volumes of superheated steam, which poses problems for operations during: Night, overcast days and winter seasons. Due to these periods of time where CSP can be ineffective, natural gas burning steam generators are partially implemented as a backup to maintain steam production levels through troublesome climates. Developments however have been made towards becoming independent of burning any fuels to create steam in thermal EOR methods through using highly heat conductive liquid or solid media as storage facilities. This includes materials such as molten salts, ceramics and concrete, which will allow heat from CSP to be utilised for steam during shorter periods of no direct sunlight such as night[13].

Although thermal EOR is the most widely used tertiary method of oil recovery in the world today, with countless mature fields harbouring high volumes of heavy oil, it would be impossible to use CSP steam generation at all sites due to unfavourable climate and environment changes. One change in environment which causes problems for using CSP thermal EOR are offshore fields, which account for a considerable amount of the worlds giant oil fields with many intermediate-heavy oil deposits, such as the Tupi field, South coast Brazil[14]. Research is being developed on the concept of having floating or fixed structures in the ocean for CSP, which would enable easy generation/transportation of steam for offshore thermal EOR projects However the environmental concerns that arise from the development of such a concept, such as potential interference with overflying

12 http://www.bloomberg.com/news/2011-08-03/oman-awards-contract-for-mideast-s-first-solar-oil-recovery-site.html
13 http://www.greenpeace.org/raw/content/international/press/reports/Concentrated-Solar-Thermal-Power.pdf
14 http://www.offshore-technology.com/projects/tupi-oilfield/

aircraft operations and possible damage to the seas ecosystem means this concept is far from commercial use[15].

The future of CSP in thermal EOR

While the use of CSP in thermal EOR is largely limited by location to heavy oil fields in areas of abundant sunshine, the compatibility of many oil fields and their locations for this technology is vast, providing a large section of the EOR market CSP steam injection can be eligible to. Venezuela is one country which relies heavily on steam thermal oil recovery with approximately 70% of their total reserves labelled as heavy oil[16], and along with their sunny climate have become a very promising area for CSP integration with thermal recovery.

The largest prospects for substantial growth of CSP in the thermal EOR market lies in Middle eastern countries, where there are no shortage of mature giant oil fields with considerable heavy oil reserves. Oman is currently invested heavily into EOR methods such as Steam Assisted Gravity Drainage (SAGD) techniques when production rates started to fall from 2001-07 for Occidental, operator of the Mukhaizna field. This brought a rise in daily oil production from 2005-10 of ten times more than before thermal recovery was introduced. Oman expect to be producing 300,000 Bopd in 2012[17]. Other countries such as Egypt and Sudan have large reserves of heavy oil, the exploitation of which is heavily relied upon through thermal techniques such as Cyclic Steam Soaking (CSS) and SAGD. By 2020, 50% of Sudan's reserves will be heavy oil[18], which will mostly need producing through thermal enhanced oil recovery.

EOR is a rapidly growing large market that is invested heavily in by all major oil companies, the majority of which goes into thermal injection projects using vast quantities of steam. CSP technology provides the cheapest way to produce superheated steam with little adverse effect on the environment, and with oil companies under increasing pressure to reduce the harm to the environment from oil production; this method provides a very commercially attractive prospect to do so. Recent successes from the company GlassPoint in this field with the adoption of its technology from major oil companies in the Middle East further confirms the viability and potential success for integrated CSP and thermal EOR in the oil industry.

15 http://www.offshore-technology.com/projects/tupi-oilfield/
16 http://www.bloomberg.com/news/2011-08-03/oman-awards-contract-for-mideast-s-first-solar-oil-recovery-site.html
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6+8. *Oil & Gas Science and Technology* – *Rev. IFP,* Vol. 63 (2008), No. 1, pp. 9-19, Enhanced oil recovery: An Overview

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