Nafta-Gaz 2024, no. 4, pp. 211–217, DOI: 10.18668/NG.2024.04.03

Possible application of solar energy to power hydrocarbon extraction and enhanced oil recovery operations in high latitudes

Możliwe zastosowanie energii słonecznej do zasilania operacji wydobycia węglowodorów i metod wspomagania wydobycia ropy naftowej na dużych szerokościach geograficznych

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ABSTRACT: As the world enters the renewable revolution, it is crucial for the petroleum industry to remain relevant in the public eye and become environmentally awareness. One potential path to achieve these goals in a progressive and beneficial way is to integrate renewable energy sources into various nodes of the petroleum industrial operations. Different ways of achieving such integration are described in the review section of the article. These include utilizing solar energy to power upstream operations and a variety of enhanced oil recovery projects, such as microbial enhanced oil recovery and others, or using solar energy downstream to supply power to pumps, gas lift apparatus, etc. The article also proposes a novel potential application of solar energy to power operations and provide long-term sustainable energy source to petroleum operations in high latitudes. The potential applicability of solar power in petroleum engineering operations far North has long been neglected due to potential unprofitability and difficulty of construction of solar power grid in such harsh climactic conditions. However, now, as the world transitions to a new reality of co-existence of fossil fuels with alternative energy sources in light of growing concerns over climate change, it is a strategic time to implement the technology in profitable and environmentally conscious way in countries that have a trustworthy environmental record and strong, robust environmental policies, like Canada, as well as in less environmentally achieving countries with milder emission reduction targets such as Russian Federation.

Key words: solar energy, petroleum engineering, integration, hydrocarbon production, high latitudes, microbial enhanced oil recovery (MEOR).

STRESZCZENIE: W miarę jak świat wkracza w rewolucję związaną z odnawialnymi źródłami energii, kluczowym zadaniem dla przemysłu naftowego jest utrzymanie swojej istotnej pozycji w oczach opinii publicznej i zwiększenie świadomości ekologicznej. Jedną z potencjalnych dróg do osiągnięcia tych celów w innowacyjny i zarazem przynoszący korzyści sposób jest integracja odnawialnych źródeł energii z różnymi obszarami działalności przemysłu naftowego. Różne sposoby tej integracji opisano w części przeglądowej artykułu. Obejmują one wykorzystanie energii słonecznej do zasilania procesów wydobywczych i różnych projektów intensyfikacji wydobycia ropy naftowej, takich jak mikrobiologiczna intensyfikacja wydobycia ropy naftowej i inne, lub też wykorzystanie energii słonecznej do zasilania pomp, gazodźwigów itp. W artykule zaproponowano również nowatorskie potencjalne zastosowanie energii słonecznej do zasilania procesów operacyjnych i zapewnienia długoterminowego zrównoważonego źródła energii dla wydobycia ropy naftowej na dużych szerokościach geograficznych. Temat potencjalnego zastosowania energii słonecznej w operacjach inżynierii naftowej na dalekiej północy nie był jak dotąd podejmowany ze względu na potencjalną nieopłacalność i trudność budowy sieci energii słonecznej w tak trudnych warunkach klimatycznych. Jednak teraz, gdy świat przestawia się na nową rzeczywistość opartą na jednoczesnym stosowaniu paliw kopalnych i alternatywnych źródeł energii w świetle rosnących obaw związanych ze zmianami klimatu, jest to strategiczny czas na wdrożenie tej technologii w opłacalny i świadomy ekologicznie sposób w krajach, które mogą pochwalić się dobrą reputacją w zakresie ochrony środowiska i silną, stabilną polityką środowiskową, jak np. Kanada, jak również w krajach o mniej rygorystycznych założeniach redukcji emisji, takich jak Federacja Rosyjska.

Słowa kluczowe: energia słoneczna, inżynieria naftowa, integracja, wydobycie węglowodorów, duże szerokości geograficzne, mikrobiologiczne wspomaganie wydobycia ropy naftowej (MEOR).

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Article contributed to the Editor: 31.10.2023. Approved for publication: 25.03.2024.

Introduction

In the 21st century demand for energy worldwide has been steadily increasing. According to BP Statistical Review of World Energy 2022, in 2021 alone primary energy demand increased by 5.8% or 31 EJ, with the developing world, and predominantly China, accounting for the lion's share of the increase (British Petroleum, 2023). This drastic increase in demand requires an adequate supply to maintain humanity's historically unprecedentedly high standards of living. This stimulates the search for an additional energy capacity which is commonly referred to as "alternative energy".

We disagree with the "alternative energy" and "energy transition" narratives, leaning more towards "energy expansion" concept introduced by Epstein of a type of symbiosis between fossil fuel derived energy and renewable energy (Epstein, 2019), for only working in a unison can they expand humanity's total energy supply which has historically been a good measure of technological development of a civilization.

It is noteworthy that though diminished or transformed, none of the previous energy sources perished completely, regardless, if a mere century or several millennia passed since humanity had first achieved harnessing its power. Now by the beginning of the second quarter of the 21st century humankind stands anew before such an energy expansion, and our priority as petroleum engineering community is to appropriately navigate these murky waters in order to achieve more efficient hydrocarbon production, reduce environmental impacts of such production, properly integrate renewable energy sources into its supply chain and itself into a rapidly changing world – a monumental task compounded by a paramount imperative of staying relevant and in good graces of both general public and regulatory authorities. One of the ways to fulfil this careful balancing act is to implement solar power to various steps of hydrocarbon production.

The review section of this article focuses on already existing proposals and implementations of solar power, such as powering thermal enhanced oil recovery projects or providing electricity to run pumping units and other day-to-day field operations. The discussion section of this article focuses on potential applicability of solar energy to power production operations and microbial EOR operations in high latitude regions that are rarely considered suitable for any solar-based powering whatsoever. The ultimate aim of the article is to encourage potential shareholders to invest in solar-powered operations in Far North.

The secondary aim of the article is to introduce a simple and affordable solution to the problem of maintenance of the comfortable living conditions for various biological cultures employed in the microbial enhanced oil recovery projects. Primary focus is on providing adequate temperatures without the need in excessive and energy consuming heating systems.

Integration of Solar Energy into Petroleum Engineering

Due to their significant energy requirements, drilling and primary recovery processes involve additional energy costs. During its brief operation, a typical drilling rig can use more than 1 MW of power (Quinlan et al., 2011). On the other hand, primary recovery processes require substantially less energy over a longer time span. Currently, the energy required for drilling and primary recovery is often provided by diesel or natural gas engines.

By incorporating renewable energy sources, the reliance on generators can be reduced, resulting in significant fuel savings. Caterpillar's 1-MW Cat® G3512 generator can be shown as an example of hybrid solutions that achieved 28,000-gallon fuel reduction over two weeks period by incorporating produced gas into their energy production, supported by lithium-ion batteries to store any excess energy (Morrison, 2021). When drilling operations are in close proximity to electrical infrastructure, they can be powered directly from the grid. This shift to electricity not only reduces noise, emissions, and traffic congestion but also allows for the integration of renewable energy through microgrid systems. Microgrids enable the integration of distributed generation, providing a versatile, reliable, and environmentally friendly approach.

In locations with abundant renewable energy sources, oil activities are routinely carried out. Oil field and well pad equipment can be converted to electric power and connected via a microgrid with an improved control system. This all-encompassing strategy has been effectively applied in far-off military bases, towns, and islands, demonstrating its suitability for business operations with predictable energy requirements and readily available resources. Such microgrids can be powered by solar PV/wind systems, energy storage, fuel cells, hydrogen, field gas, or even grid electricity. With this strategy, leakage and emissions are reduced, outages are more resilient, and costs are maximized.

The use of renewable energy to operate artificial lift pumps is a prime illustration of integrating renewable technologies into upstream operations. When natural well pressure is insufficient, pumps such as rod beam pumps are crucial for oil extraction. Over 80% of oil production wells in the western United States use rod beam pumps, which are widely used in several regions. A rod beam pump can be efficiently run on solar power in conjunction with a capacitor to store regenerative power during the pump's downstroke. Endurthy et al.

(2016) conducted tests that showed significant potential energy savings, and commercial use of solar-powered oil pumps had already commenced. By incorporating battery storage, solar power pumps can be applied to off-grid locations with sufficient sunlight, further enhancing their applicability.

In summary, there are several advantages to electrifying drilling and primary recovery operations using renewable energy and microgrid systems, including decreased fuel use, lower emissions, increased resilience, and cost reduction. These developments open the door for a more efficient and sustainable method of conducting oil operations.

The study by Jenkins et al. (2019) investigates the potential of a solar steam generation system for utility-scale implementation in Libya's oil industry. The study utilizes parabolic troughs as solar collectors and evaluates the technical and economic performance of the system using the System Advisor Model (SAM). The research demonstrates that solar energy integration in enhanced oil recovery (EOR) methods is feasible and can be considered an add-on to oil plants in Libya due to the country's abundant solar resources. The study highlights the advantages of Glass Point's enclosed trough technology, which delivers steam at competitive costs, withstands harsh oilfield environments, and follows oilfield best practices. The methodology includes an assessment of solar potential in Libya and the design details of the solar steam plant system. The estimated thermal energy output of the system is 219 GWh per year, with an efficiency of 35%. The economic analysis shows that the proposed solar steam generation system has a cost of 6 $/KW. Solar EOR offers environmental benefits by reducing emissions and contributes to the sustainability of oil operations. The study concludes that solar energy integration in the oil and gas industry is technically viable, providing financial advantages and extending the life of oil reservoirs. This case study serves as an example of successful solar energy integration in EOR processes, showcasing the feasibility and benefits of utilizing renewable energy in the oil industry (Jenkins et al., 2019).

Unfortunately, no commercial scale industrial applications exist for such operations in high latitudes, only urban scale, which is the primary aim of this article – to open a discussion for potential industrial investors to implement (Hassan et al., 2011; Lobaccaro et al., 2017; Kouhestani et al., 2019).

The use of solar energy to power enhanced oil recovery (EOR) and hydrocarbon extraction operations in northern (high latitude) regions has a significant potential to cut harmful emissions and minimize adverse environmental effects. The extraction and EOR processes can greatly reduce their impact on climate change by using solar energy instead of conventional fossil fuel-based energy sources. When compared to conventional energy sources, solar energy systems produce power without emitting any greenhouse gases, which reduces overall emissions of carbon dioxide and methane. In locations where hydrocarbon extraction activities are common, the switch to application of renewable energy can help slow down climate change and enhance air quality.

Solar energy can also aid these operations financially. It can replace costly fuel sources, resulting in significant long-term cost reductions. High latitude areas with plentiful sunlight can provide excess power that can be used efficiently or even sold back to the power grid, generating new cash streams for EOR and extraction projects. Not only can greenhouse gas emissions be decreased by utilizing solar energy in hydrocarbon extraction and EOR processes, but there are also possible financial benefits due to cost reductions and potential revenue production from excess electricity. The utilization of solar energy is a viable possibility due to this synergy of environmental and economic advantages.

Application of solar energy in far North Oil Fields

According to Halabi et al. (2015), about one-tenth of produced oil is expended during its production, processing, and transportation. The numbers are even higher for heavy oil production – up to a quarter of produced hydrocarbons goes to fuel the production process (Halabi et al., 2015). This is further exacerbated by the fact that pre-production activities consume significant amounts of energy as well: for example, for drilling of a single well, between roughly 180,000 and 300,000 liters of oil are used. Furthermore, there is a clear trend to reduce in the NER (net-energy ratio) – the ratio of energy produced to the energy used to produce it – for each field studied by Tripathi and Brandt the NER diminished by 46% to 88% over the last forty years (Tripathi and Brandt, 2017). The same trends at the faster pace are observed by Freise (2011) for conventional oil production in Canadian fields – a double decline in span of just two decades. The diminishing NER is a result of a combination of declining production rates and rise in energy costs on various EOR projects.

To combat these trends amid relatively high oil prices and extremely high natural gas prices, it has long been suggested to expand the energy supply to petroleum operations via replacing conventional energy sources with renewables, primarily solar energy. Nowadays, as seen in Figures 1, and 2, the cost of RES has dropped many folds and is profitable in regions such as Gulf countries, which are due to their geographical position prone to high and consistent insolation.

Solar technologies designed for high latitudes face unique challenges due to reduced sunlight intensity and shorter daylight hours. However, significant strides have been made in

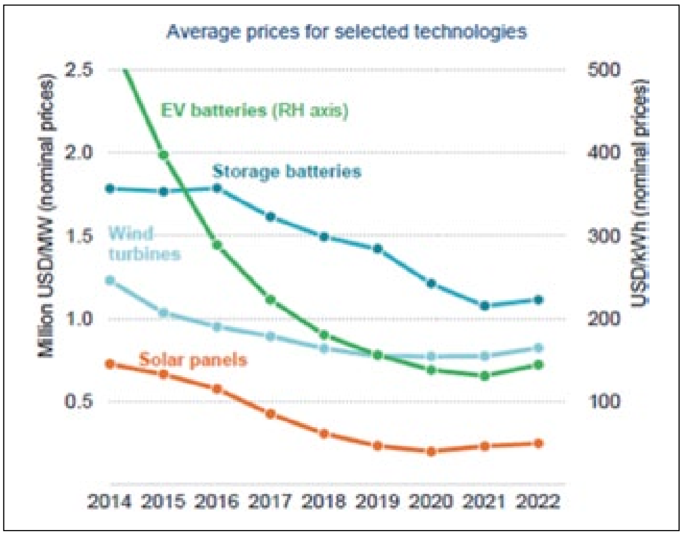

Figure 1. Average prices for solar and wind energy sources, as well as storage technologies, 2014–2022 (World Energy Outlook, 2023)

Rysunek 1. Średnie ceny energii słonecznej i wiatrowej oraz technologii magazynowania, 2014-2022 (World Energy Outlook, 2023)

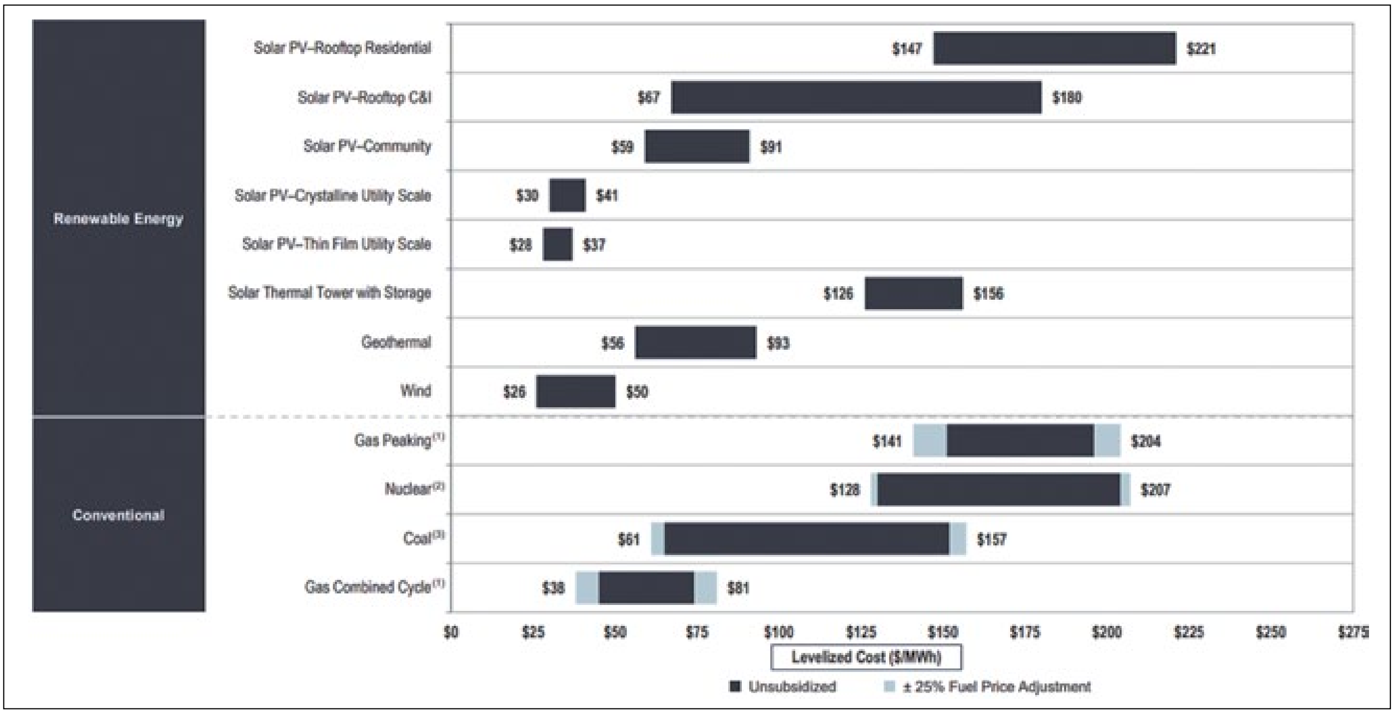

Figure 2. Costs of different energy sources per MW/h (Lazard, 2023)

Rysunek 2. Koszty różnych źródeł energii dla MW/h (Lazard, 2023)

optimizing solar energy utilization in these regions. Several technologies prove suitable for high latitudes, including concentrated solar power (CSP) (Lobaccaro et al., 2017), bifacial solar panels (Jouttijärvi et al., 2022), etc.

Concentrated Solar Power (CSP) systems utilize mirrors or lenses to concentrate sunlight onto a receiver, generating heat. This thermal energy can be stored and utilized for power generation, ensuring continuous operation even during periods of limited sunlight. The incorporation of thermal energy storage enhances the viability of CSP in high-latitude regions. Bifacial solar panels have the capability to capture sunlight from both sides, making them advantageous in regions with lower solar irradiance. They can gather reflected sunlight from surrounding surfaces, boosting overall energy production and maximizing efficiency, particularly in high-latitude environments.

Tilting solar panels at an optimal angle and employing tracking systems that follow the sun's path throughout the day can enhance solar energy capture in high-latitude regions. These adjustments allow panels to receive sunlight more directly, compensating for the lower angle of incidence and shorter daylight hours.

Implementing energy storage systems, such as batteries or thermal storage, helps bridge the gap between energy production and consumption in high-latitude areas. These technologies enable the storage of excess energy generated during periods of abundant sunlight, providing a reliable power supply during low-sunlight periods. By combining these solar technologies with efficient energy storage solutions, the adoption and effectiveness of solar energy in high-latitude regions can be expanded, overcoming the challenges posed by reduced sunlight availability.

Since there has been recent significant progress in supplementing fuel burning with solar and other alternative energy sources across the globe, the novelty of this article lies in suggesting the use pf similar techniques in much higher latitudes in regions that do not experience high clouding, thus prone to comparable if slightly lesser levels of Global Horizontal Irradiance (GHI – total solar irradiation incident on a horizontal surface (Quinlan et al., 2011)), such as Alberta, Canada; Russian Siberia; Alaska, USA, etc. These operations remain profitable as shorter winter operating time frames are balanced out by much longer solar days for the spring-summer season.

As the climate change develops in its earnest, the costs of logistics to faraway locations such as Siberia or Northern Alberta can safely be assumed to go down significantly, especially for Siberia as starting in 2024, the first commercial maritime shipping operations are expected to run on a regular basis through the northern corridor (a safe year-round ice-free passageway though the Arctic Ocean near Russian coast – result of the global climate change). Even today, Russia conducts maritime trade through this corridor albeit with certain challenges, namely, the need for an icebreaker to remove still present ice. This need would diminish and is estimated to disappear entirely by the mid-2030s, driving costs down significantly.

Thus, taking into account GHI figures (examples for Alberta, Canada; Tatarstan, Russian Federation – given as a an example of an oil-rich region with prolonged and harsh winters, albeit not as far north as Alberta; and Algeria for comparison purposes are given in Figure 3), as well as a prospect of significant decline in logistics costs, an argument can be made on the profitability of implementing solar panels for fueling energy demands of petroleum operations in far northern regions. Such supplementation would bring not only significant environmental benefits, but the saved oil and natural gas previously used for fueling drilling, production, refining, and transportation operations could be commercialized at significant profits. Additionally, this approach would improve the public perception of the industry. Currently, petroleum engineering has become controversial in public eye and is in desperate need of an overhaul of the public opinion, even though the industry is on the forefront of the efforts towards decarbonization and green technologies, and has become one of the greenest of all the natural resources extraction industries.

Global Horizontal Irradiance (GHI) is the amount of terrestrial irradiance falling on a surface horizontal to the surface of the earth. Figure above illustrates that on 50 percent of days in a year, Tatarstan has 10% less solar energy hitting the surface than Alberta, and roughly half that of Algeria.

Another type of operation that could theoretically be powered by solar energy is microbial enhanced oil recovery

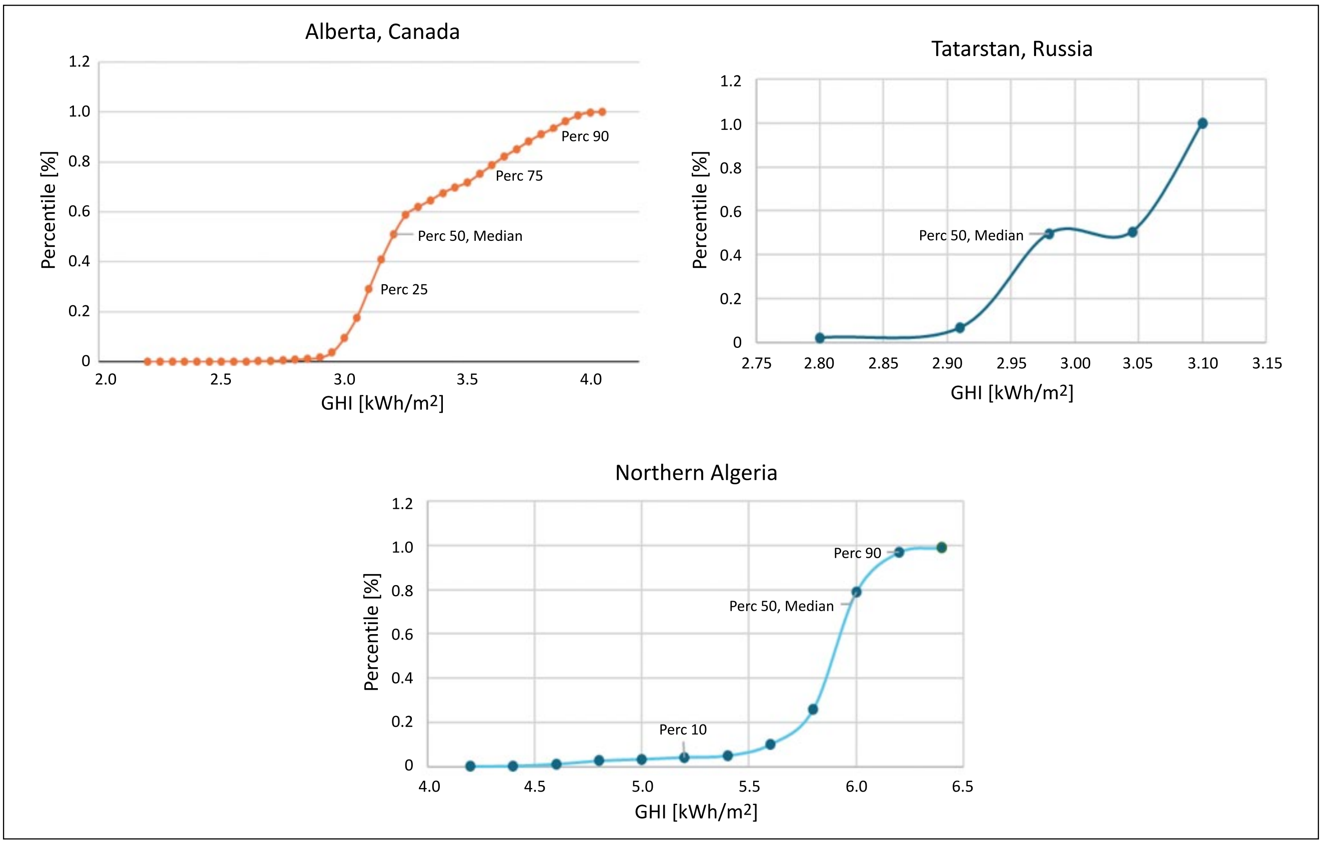

Figure 3. Cumulative distributions of global horizontal irradiance for the province of Alberta, Canada, Republic of Tatarstan, Russian Federation, and Northern Algeria (source: Global Solar Atlas)

Rysunek 3. Skumulowane rozkłady globalnego nasłonecznienia na płaszczyźnie poziomej dla prowincji Alberta w Kanadzie, Republiki Tatarstanu w Federacji Rosyjskiej oraz północnej Algierii (źródło: Global Solar Atlas)

(MEOR). MEOR is a technology based on manipulating the function, structure, or both, of biological environments existing in oil reservoirs (Sen, 2008).

Such microorganisms that are introduced into formation require certain conditions of viability. Namely, the right temperature and access to water and nutrients.

Solar energy, being black body radiation, i.e., thermal radiation, can be directly focused on the bacteria containers in the northern regions, thus eliminating the need for additional complex and expensive heating equipment, achieving a significant cost reduction in the process. A simplified flow diagram for such a process is given in Figure 4.

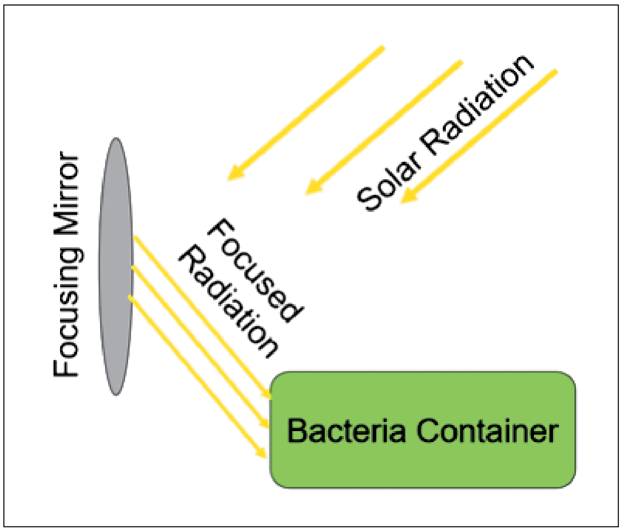

Figure 4. Simplified flow diagram for solar heated bacteria storage

Rysunek 4. Uproszczony schemat przepływu dla pojemnika z biopreparatem ogrzewanego energią słoneczną

Assuming that a typical drilling and MEOR operations will in sum consume around 200 GWh of energy, and that typical PV panel produces around 1.5 kWh/day (547.5 kWh/year) it is not hard to calculate that a battery of around 400,000 panels would be required to fully power such an operation. This number could be reduced by partially employing other, more conventional sources of energy.

Conclusions

According to the International Energy Agency, global oil demand is expected to rise at least for the foreseeable future. This fact, alongside the need to combat climate change and improving public perception, should prompt the fossil fuel industry to consider novel and unique solutions and opportunities presented by the changing climate.

The following summary can be drawn from the discussion above.

1. Data suggests only marginally lower GHI in those regions in comparison to North African region, which could be compensated by longer availability during periods between spring and autumn equinoxes.
2. Canada looks more promising than Russia for implementing this strategy due to higher irradiation levels.
3. Direct heating of microbial storage for MEOR is another viable strategy to implement solar power in high latitudes.
4. Further feasibility and economic analysis have to be performed to assess the overall viability of proposed methods.

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