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Repurposing Abandoned Oil and Gas Wells for Geothermal Applications

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Abstract— This paper focuses on providing insights and knowledge on repurposing abandoned oil and gas wells for geothermal applications. Abandoned wells emit alarming amounts of greenhouse gases and pose serious health hazards and they require a thorough procedure for decommissioning for two reasons. The ordinary cement used in sealing of the wells used in decommissioning deteriorates with time and often leak harmful These obstacles can be addressed by retrofitting abandoned wells for geothermal energy utilization. This paper presents a comprehensive overview on the available conversion technologies, available case studies along with challenges and opportunities pertaining to repurposing for geothermal development. The proposed technology presents an attractive alternative that will reduce the overall costs of developing a geothermal system and decrease the negative environmental impact of abandoned oil and gas wells.

Keywords—Sustainable and renewable energy, geothermal energy, abandoned hydrocarbon wells, well conversion,co-production

I. Introduction

Energy demand globally is increasing exponentially with population growth, industrialization, and economic growth. This demand is projected to grow by approximately 50% between the years 2018 to 2050 [1]. Fossil based energy is attributed to high greenhouse gas emissions and alarming environmental effects and is subjected to price fluctuation; thus, alternative renewable and sustainable energy resources with lower environmental impacts are needed such as wind, solar, biomass, and geothermal among others.

Geothermal energy provides a pathway to address and mitigate climate change. It consists of the trapped energy within the earth and presents an exhaustible source of energy. It is a secure, reliable, and flexible energy that can be employed for industrial, commercial, and residential applications and can guarantee grid stability, affordable energy sources, efficient heating and cooling, and improved air quality [2, 3]. The wider deployment of geothermal applications is hindered because current geothermal plants are limited to locations with high geothermal gradient and hydrothermal resources and suffer from high capital investment cost [4]. Therefore, reducing the drilling costs would accelerate the development of this technology, and abandoned wells can be utilized to serve for this purpose. In the United States, 2.3 million onshore abandoned wells are reported, and studies suggests that this number is an underestimate due to lack of appropriate documentation prior to 1950 [5, 6, 7]. At the end of production, laws and regulations require that a well should be properly plugged, either by cement casing or mechanical plugs. Despite the requirements, orphaned and deserted wells are reported in the national database, which should be plugged by the corresponding state.

In this review, the risks that abandoned wells present are listed, the available technologies are explained, available case studies are discussed, and the challenges and gains are presented.

II. Abandoned oil and Gas Wells Risks

Abandoned oil and gas wells provide conduits for liquids and gases within the hydrocarbon bearing formations to migrate to the atmosphere or potable aquifers as shown in Fig. 1. Extensive studies suggest that abandoned wells, plugged or left open, are associated with methane (CH_4) emissions [5, 6, 8]. Methane is described as a harmful greenhouse gas, with a global warming potential (GWP) of 28 to 36 greater than the impact of carbon dioxide (CO_2) over a 100-year period and 84 to 86 times over a 20-year period [9]. Results in Pennsylvania basin shows that emissions from abandoned oil and gas wells contribute to 5 to 8% of the annual anthropogenic methane emissions in the state [6]. Similar studies in the Powder River Basin in Wyoming, the Denver-Julesberg Basin in Colorado, the Uintah Basin in Utah, and the Appalachian Basin in Ohio show that methane emissions from abandoned wells ass to the regional CH_4 emissions [5]. Currently, methane emissions are underestimated in Canada by 150% and in the U.S. by 20%. Additionally, improperly sealed or unplugged wells provide pathways for the methane to migrate to the groundwater and pollute it. Studies deploying monitoring wells near hydrocarbon basins shows shallow groundwater contamination by methane leakage [10,11]. Migrated methane can lead to pressure build-up within fault zones and pore formations, leading to explosions exceeding the critical pressure of the zone. Many cases associated with explosions due to methane leakage have been recorded [12, 13]. Another hazard abandoned wells are associated with includes health issues. A strong correlation between people living at proximity to hydrocarbon wells and increased reported dermal and respiratory symptoms exists [14, 15].

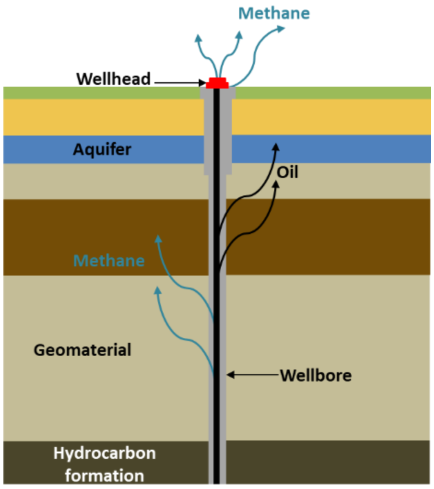


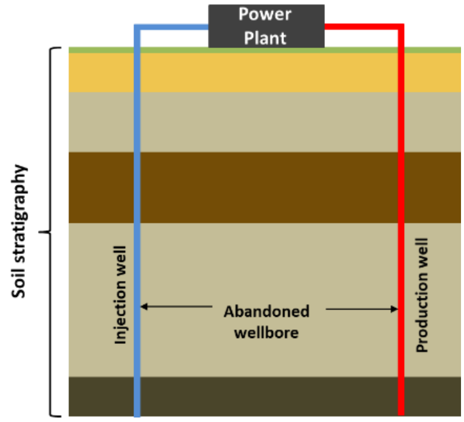
Figure 1. Pathways for gas and liquid leakage from abandoned hydrocarbon wells

III. Available Technologies for Repurposing Hydrocarbon Wells

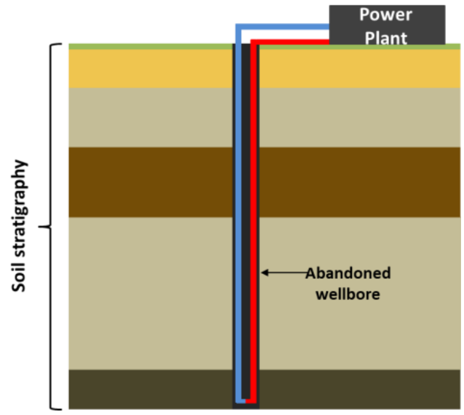
To benefit from the existing infrastructure to extract geothermal energy, utilizing and retrofitting hydrocarbon wells can be performed by two approaches: (1) co-production of heat from the extracted fluids in hydrocarbon fields, and (2) conversion of an abandoned well into a geothermal well.

Co-production refers to the simultaneous production of hydrocarbon and geothermal energy from a mature oilfield by extracting the heat trapped in the co-produced geothermal fluid during operations. This process becomes economically viable in mature oil and gas operations, where water cut, indicating the ratio of water produced to the total volume of liquids extracted during oil and gas operations, is as high as 99%. The separation of the large water volumes from the oil is a costly operation, as well as that from water treatment and disposal [16, 17]. The temperature of the water extracted ranges between 65 to 150 ℃ and can be converted into heat and/or electricity. [18] proposed a screening criterion, that evaluates the geological, reservoir, production, and economical aspects, to determine the feasibility of harnessing low-temperature geothermal energy from mature hydrocarbon reservoirs.

Conversion is defined as the full transformation of a well from hydrocarbon production to geothermal production. When a hydrocarbon becomes unprofitable, the operator must decommission and plug the well. Converting the well will eliminate the incurred costs of plugging and decommissioning and save the exploration and drilling costs for geothermal applications. To extract the geothermal energy, two configurations are proposed in the literature (1) open loop system or (2) closed loop system as shown in Fig. 2(a) and 2(b) [19]. A minimum of two wells, one for injection and one for extraction, is needed when an open loop system is installed. This system operates by pumping a fluid in the injection well, where it circulates and heats up within the reservoir to be then produced from the extraction well. Many factors determine the efficiency of this system, and they include flowrate and hydraulic and thermal properties of the reservoir. This system generates relatively high energy output. The setback of this system is that it is site-specific, limited to areas where two abandoned wells are close to each other. The other configuration is a closed loop system and is only applicable when the well is no longer producing hydrocarbon. Compared to an open system, a closed system lead to a lower heat extraction performance. However, this system has numerous advantages such as a need for a low pumping work, absence of scaling of the pumps and pipes from the minerals in the extracted brine, wide selection of working fluid, no requirement for water management system, among others. For this system, two types of heat exchangers are available: (1) a U-tube heat exchanger and (b) a double pipe heat exchanger. For a U-tube system, the mass flowrate, well depth, heat exchanger length, and inlet temperature affect the system’s performance [20]. A double heat exchanger system has a larger heat transfer surface area than that of a U-tube system; thus, having a higher efficiency.



(a)



(b)

Figure 2. A configuration of (a) an open loop system (b) a closed loop system

IV. Case Studies

Case studies to explore the feasibility of utilizing hydrocarbon wells for geothermal applications are performed. Co-production field tests have been carried out. However, for a full conversion of an abandoned wells, field tests are limited. This section will present some of these studies.

A. *Huabei Oil Field*

The Huabei oil field is located in Huabei, China. The project has been operating on a commercial scale since 1978. The reservoir consists of fractured carbonate rocks with a temperature of approximately 120℃. During production, water cut is reaching 98% and the water temperature is 110 ℃. The thermal energy trapped in the extracted water can be utilized, and the project generates a combined heat and power of 400 kW, saving 2000 tons of fuel and 6000 of CO_2 emissions [18].

B. *Naval Petroleum Reserve No. 3*

The Naval petroleum reserve No.3 is in Wyoming, United States. The project aim is to investigate the power production from the steam wasted from the oil production. The operation in that project started in 1920, then shut down for a long period of time, to then resume work in 1976. The reservoir temperature is approximately 110℃. The project wastes energy within the extracted water equivalent to 22 MW of electrical power. Results from the project generated a net power output of 171 kW and 185 kW during the first and second phases, respectively, showing a promising future for the proposed technology [21].

C. *Los Angeles Basin*

The Los Angeles Basin is in California, United States. The average water cut in this field in 97%. The geothermal gradient is 28℃/km [22] studied the potential power production from the Wilmington, Beverly Hills, Inglewood, Long Beach, Santa Fe Springs, Seal Beach, Sawtelle, Rosecrans, and Huntington fields. Results are promising for Seal Beach, Sawtelle, Rosecrans, and Huntington oilfields and not economically or technically feasible for the others.

D. *The MEET Project*

The Multidisciplinary and multi-context demonstration of Enhanced Geothermal Systems exploration and Exploitation Techniques and potentials (MEET) project is in Europe and seeks to utilized low temperature resources from oil and gas operations to generate electricity. This project currently performs small-scale demonstration tests. A project located in the Southwest France aims to test the feasibility of co-producing electricity from active wells to be consumed on site. Another project in the South-East plans to convert heat into electricity at the wellhead [19].

V. Challenges

Numerous challenges are associated with retrofitting abandoned oil and gas wells. A reliable screening process is recommended to ensure the efficacy of the system. An economical system requires a high geothermal gradient, suitable depth, and adequate hydraulic and thermal properties of the reservoir. For certain projects, increasing the well depth is necessary to achieve the desirable output. Corrosion from the minerals from the geothermal brine can be problematic. It can lead to clogs in the heat exchangers, requiring periodic maintenance and cleaning.

A closed loop configuration might dictate widening the diameter to accommodate for the heat exchanger. Increasing the diameter might also enhance the heat extraction rate. An open loop configuration is more challenging. The well layout is critical and determines the economic feasibility of the project.

Another challenge is that the extracted heat is low; thus, it is necessary to be close to the prospective customers to limit heat losses within the transmission pipelines. For electricity generation, large scale production is not achievable with the low brine flow and relatively low temperature. However, this should be evaluated for every project independently.

Other risks associated with well conversion are that the design of the oil and gas well is not suitable to sustain geothermal applications and causing technical problems. Also, the integrity of the well casing and cement and the sealing between the wellbore and the surrounding subsurface should be evaluated to guarantee exploitation durability.

VI. Impacts of Repurposing Abandoned Wells

Abandoned oil and gas wells are abundant and require money to be plugged and decommissioned. To avoid the incurred costs and extend the economic life of a well, repurposing abandoned wells for geothermal applications can have economic and environmental impacts.

Currently in the U.S. government, the social cost of methane (SCM) emissions is $4,822. To offset this cost incurred on the government, retrofitting wells can decrease the emissions; thus, the SCM.

In mature oilfields where water cut exceeds 95%, revenues from the extracted oil and gas decreases and operational costs, including water treatment and disposal, increases. Co-production is an attractive solution to add to the profit margin and extend the lifetime of the oil field. Also, the fluid extracted carries thermal energy that can assist in supplying for the electrical needs of the plant, or it can be sold to the grid for profit.

Retrofitting a hydrocarbon well for geothermal purposes can save reconnaissance, exploration, and drilling costs and time, which are a substantial portion of a geothermal project. Approximately, it takes up to 6 years to perform these phases in a new geothermal project, which can be reduced, and the geothermal plant can operate sooner.

Repurposing abandoned wells can lead to a wider deployment of geothermal systems for electricity generation, which can deem to produce savings in electricity costs for the clients. Studies in north America, Europe, and Asia, shows that electricity cost is reduced by 4 ¢/kWh when this technology is employed [23].

A geothermal system produces 99% less CO_2 compared to a conventional fossil fuel plant. Retrofitting abandoned wells can accelerate the shift for geothermal applications, yielding to achieve the goal set forth by the GeoVision and decrease emissions by 516 million metric tons (MMT) of CO_2 in the electricity sector and 1,281 MMT of CO_2 from heating and cooling [2].

VII. CONCLUSION

In this paper a review on repurposing abandoned oil and gas wells to be utilized for geothermal applications is presented. The risks that abandoned wells pose are highlighted, current available technologies with case studies are discussed, and the opportunities and challenges are listed. Specific conclusions drawn from this work are as follows:

- Factors affecting the economic and technical feasibility of a co-production project are the bottom-hole temperature, flow rate, and the water cut ratio.
- Factors affecting the economic and technical feasibility of a full conversion project are the bottom-hole temperature, flow rate, and petrophysical parameters.
- Policies and law that regulate the conversion process are necessary to increase the development of this technology and attract investors to finance it.
- Evaluation on a case-by-case basis is important to accurately characterize the subsurface properties, and assess the operational, technical, and economic feasibility of the project.
- Currently in the United States, many states have the available infrastructure to deploy the proposed technology.

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