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Repurposing Abandoned Hydrocarbon Wells for Geothermal Power in Northern Bangladesh: A Feasibility Study Toward Affordable and Sustainable Energy

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ABSTRACT
Bangladesh currently relies heavily on its domestic natural gas reserves to meet the majority of its energy demand, with most power plants operating on gas-based systems. As the gas reserves continue to deplete, there is an increasing need to diversify the country's energy portfolio. In recent years, initiatives such as pilot projects in solar and wind energy, along with the development of the Rooppur Nuclear Power Plant, have marked significant steps toward a more sustainable and diversified energy future. Nevertheless, meeting the growing electricity demand of Bangladesh's large and densely populated society will likely require additional, reliable energy sources. Geothermal energy presents a promising solution in this context, as it can provide continuous, 24/7 baseload power-an advantage over intermittent renewables such as solar and wind. Preliminary geophysical studies conducted in selected regions of Bangladesh have indicated favorable geothermal gradients, suggesting the potential viability of geothermal power development. The geothermal potential varies across the country, depending on local geological and thermal conditions. This study explores the different geothermal resources across the globe and how they are being utilized in different methods and for different purposes. The study aims to evaluate the feasibility of establishing a geothermal power plant in the north of Bangladesh by identifying the most geologically favorable locations and recognizing the resource conditions. Addressing the economic and technical challenges revealed from the previous geothermal assessments in the country, the study proposes the repurposing of abandoned hydrocarbon wells in the north, thereby reducing the high expenditure typically associated with drilling new deep wells. An optimal plant design (binary cycle) employing the Organic-Rankin cycle (ORC) technology is analyzed, and an estimate of potential power generation capacity up to 5.34 MW is shown in this paper. The findings are intended to support long-term energy planning by showcasing geothermal energy's potential as a reliable supplemental baseload source, offering local energy stability and contributing to the country's broader sustainable energy goals.

Keywords: Geothermal power, Energy, Renewables, Binary cycle, Repurposing

1. Introduction

Geological studies have shown elevated geothermal gradients in Bangladesh offering geothermal energy as an alternative source for power generation. In particular, studies have identified promising geothermal prospects in the south-east and north-western Bangladesh. Temperature logs from exploratory hydrocarbon wells showed promising temperature gradient in favor of geothermal energy extraction. Geothermal energy is being utilized around the world for direct and indirect uses [1].

In high-temperature geothermal regions with increased tectonic activity like in the United States, Indonesia, and the Philippines geothermal heat is converted into electricity through power plants [2]. Countries like Iceland, Turkey, and China use geothermal energy directly in district heating systems, greenhouse heating, aquaculture, industrial processes [3]. Depending on the type of geothermal reservoir from where the heat is extracted, Geothermal power plants established around the globe can be categorized into three types- dry steam power plants flash, steam power plants, and binary cycle power plants. Most operating geothermal plants in the world currently are flash steam or binary cycle, with dry steam being rare [4]. Heat can accumulate in the subsurface in different forms. In high-temperature volcanic regions natural hot water or steam reservoirs are found usually 1–3 km deep underground. Dry steam power plants or Flash steam power plants are commonly established for utilizing the resources in such reservoirs. Low-temperature-geothermal resources with reservoir temperature below 90°C are usually found in shallow aquifers or permeable rock formations, often within 1 km of the surface [4].

Binary cycle power plants have been proved the most efficient for these geothermal reservoirs. The Cooper Basin in Australia, the Cornwall region in the UK, western United States, Rhine Graben in Germany and France are known for high-temperature impermeable rock formations at depths greater than 3 km with high geothermal gradient but fluid pathways absent or minimal in the formations. Enhanced Geothermal System (EGS), a heat extraction technology that allows extraction of heat by injecting water into the ground and creating an underground heat exchanger, is adopted for geothermal power plants in these hot dry rock formations serving as geothermal resource. The Soultz-sous-Forêts Geothermal plant in France has utilized EGS system in the with 1.7 megawatts electrical (MWe) capacity [4]. The U.S. Department of Energy is conducting a Geopressured-Geothermal research program in the Gulf Coast and has achieved many significant findings that disproved many

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historical perceptions that had previously limited industry's interest in developing this resource. Though in today's economic market Geopressured reservoirs may not be commercially profitable to exploit, the rapid advance of technology in all its different aspects could potentially make it attractive in future [5].

The various types of geothermal heat accumulation in different geological location across the globe calls for multifarious extraction methods and use. Many studies have been conducted so far in context of Bangladesh with a view to diversifying the country's energy resources. Geothermal energy development in Bangladesh requires more extensive research on resource feasibility, extraction methods and suitable technologies as our country is committed to join the transition to renewable energy and achieve its future energy goals.

1.1 Geothermal Resources of Bangladesh

At Barapukuria a temperature of, 40.5°C was encountered at a depth of 380m and 52°C at a depth of 440m. A high temperature gradient of 48.7°C/km is observed here. Approximately the temperature at the depth of 4000m is calculated as 210°C. A study conducted on the geothermal potential in the Barapukuria found that, based on a 60°C reservoir temperature, a significant gross thermal energy potential of 6.17286 x 1017 Joules translates to a gross power capacity of 56.388 MW [6]. Hot springs have been observed at Barbarkund and Gobaniya Chara in the Sitakund anticline with temperatures of up to 35 o C.[7]. In the North, the groundwater of the basement aquifer of Madhyapara is marked by higher temperature (40.4°C) than the annual mean surface temperature of about 24.7°C [8].

A study of Bottom Hole Temperature (BHT) of 13 deep wells drilled for petroleum exploration in northeastern part of Bangladesh show very encouraging results [9]. In the Southeast deep sedimentary basin area, potential thermal gradient was obtained at Shahbajpur 1 well at a rate of 29.5°C/km located in Hatiya trough followed by Saldanadi 1 well at a rate of 27.2°C/km. [10]. The northwest having different geological aspects such as the hydrogeological settings, seismicity and earthquakes, cluster of basement faults and surface thermal anomalies indicate the existence of potential geothermal reservoirs at only a depth of a few kilometers below the earth's surface. The geothermal gradient in this region ranges from 20.8 to 48.7 °C /km [9].

The Geological Survey of Bangladesh drilled a thermal exploratory well at Thakurgaon and observed a temperature gradient of 34.2°C/km at a depth of 500m, warm water, up to 36°C. A private company had planned to set up Bangladesh's first geothermal power plant with a capacity to produce 200 MW. The company Anglo MGH Energy said it had sought government approval to establish the plant by digging 28 deep tube wells to lift hot steam [11]. The project however, was not realized as the idea of lifting hot steam from that area is not feasible.

Direct steam production does not seem a possible method for geothermal power generation from the low-temperature heat sources in Bangladesh. The design of a geothermal plant must consider the challenges associated to commercially extracting heat for electricity generation from these areas with low temperature gradient and employ technology that will allow the utilization of the underground heat in an economic way. Binary cycle power plants have been proved to efficiently utilize the heat in low temperature geothermal reservoir worldwide. The findings from the geological studies in the northern Bangladesh shows similar geothermal potential.

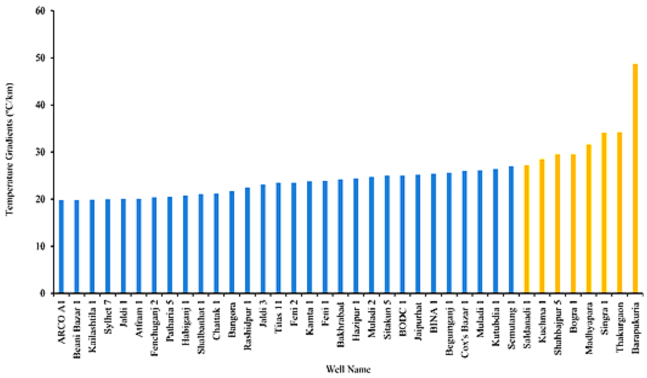

Fig-1: Geothermal Gradients at different wells in the northwest (yellow) and southeast regions (blue) of Bangladesh [9].

Recent advancements in cycle design and thermodynamic optimization have improved the thermal efficiency of geothermal power systems through the use of a variation of specially selected working fluids. This study investigates the possibility of these innovations to utilize the heat accumulated at the bottom hole of the abandoned wells in an economical way and allow the wells to be repurposed for clean and sustainable energy.

1.2. Abandoned Deep wells in the North

Northwest part is the vital part for geothermal map of Bangladesh. For hydrocarbon exploration purposes, four deep wells have been drilled in the Bogra slope at distances of 22 – 26 km: Singra to the southwest, Bogra to the northeast and Kuchma in between. In 1981, Petrobangla observed 150°C bottom hole temperature at 4100 m Singra-1 well in the Bogra Slope [12]. The temperature data make this area seem promising for geothermal exploration.

A previous study on utilizing these wells had found that the litho-stratigraphic correlation between the wells Singra, Kuchma and Bogra showed vertical displacements related to faulting and the occurrence of potentially permeable lithologies at depth where temperatures are above the minimum required for electricity production [12].

Table-1: Geothermal gradient of Northern exploratory wells

Serial No	Well name	Gradient ⁰C/km
1	Kuchma 1	28.5
2	Shalbanhat 1	20.8
3	Jaipurhat	25
4	Bogra 1	29.5
5	Singra 1	34.1
6	Madhyapara	31.6
7	Thakurgaon	34.2
8	Barapukuria	48.7

The current study investigates the technical aspects of repurposing the wells for geothermal energy extraction and commercial scale power generation. Most of the expense for establishing a geothermal power plant goes in drilling. To economically extract the low temperature resource in the north, utilization of abandoned hydrocarbon wells is preferred. Amongst the abandoned hydrocarbon wells in the north, the Singra wells have the highest temperature gradient. The three exploratory wells in Singra were sealed with cement plugs when it was proved that hydrocarbon extraction was not economically feasible. The power plant design in this study considers the Singra wells with the highest temperature gradient of 34.1°C for calculation of the proposed plant's capacity and efficiency

1.3. Repurposing Abandoned Wells

Several pilot projects repurposing oil and gas wells for geothermal extraction have been completed. Small-scale power generation from co-produced fluids has been successful at some oil fields. A coproduction geothermal system is a geothermal system that employs fluids that are produced along with oil or gas. Denbury's Laurel Oilfield in Mississippi, generating power from coproduced fluids from a depth of 2900m using an electric submersible pump, producing 16m3/day of oil and 636 m3/day of water, corresponding to 98% water, at low temperature (95 C) and flow (648m3/day) [13]. The ORC unit used R245FA fluid and produced an average of 19kWe of power and a maximum of 22kWe. In China, a low temperature geothermal plant employs coproduced resources from the Huabei Oilfield [14]. The geothermal plant, with a water-cooled screw expander unit that used R123 as the working fluid, generated 310kWe utilizing co-produced water from eight production wells at 33 kg/s and 110 °C.

In North Yorkshire UK, the first commercial-scale demonstration of turning a former gas production site into a hub for clean energy was successful in 2023 [15]. A company named CeraPhi Energy employed a closed loop well system where conduction of underground heat through fluid circulated within a 2-inch diameter HDPE pipe and heat pumps was utilized for direct use of geothermal energy in 300 homes in the locality. The well system reached down to 2000 m into the abandoned wellbore where temperature reached up to 90 °C. The well system design was made to sustain such high temperature.

When repurposing deep wells for geothermal applications, it is essential to design a well system capable of withstanding high-temperature conditions and chemical degradation over long operational periods. The casing, tubing, and surface piping materials must be carefully selected to resist corrosion caused by minerals and dissolved gases which are often present in geothermal brines. Additionally, scaling-the deposition of minerals like silica, calcium carbonate, and sulfates-can significantly reduce heat transfer efficiency and obstruct fluid flow. These factors necessitate further site-specific detailed studies on material compatibility, fluid chemistry, and mitigation strategies. Before retrofitting an abandoned oil or gas well, a comprehensive well integrity assessment and repair program should be carried out. Long term well maintenance is necessary.

1.4. Geothermal power plants

Geothermal power plants mainly consist of three established configurations, Binary Cycle power plant, Dry Steam power plants, and Flash Steam power plants. Among these, dry steam power is the simplest and oldest system where steam having 150 °C or more is used to turn the turbines. For this system, two wells are needed for rising the steam and injecting the water. Water is injected, which contacts the high-temperature rocks and produces steam that is pumped through the production well. The water is recycled in a closed-loop system. In flash steam power systems, hot and highly pressurized water is pulled into a lower pressure tank by using flash steam stations to run the turbine. This requires temperatures of >180°C and produces electricity in a more efficient way than the dry steam process. In a binary cycle configuration, the vapor is produced by transferring heat into a low boiling point organic fluid. The advantage of this type of power plant is that it can work at reduced temperatures. The typical efficiency lies within 10–13% [16]. The binary cycle power plants have been proved to efficiently utilize the heat in low temperature geothermal reservoir. The northern Bangladesh shows similar geothermal potential. Hence, we suggest a binary cycle power plant for efficient and feasible extraction of geothermal heat in the northern area of the country.

2. Methodology

With the assumption of a linear increase in temperature with depth, the temperature of any depth can be measured by the following equation:

$$T_z = T_o + T_g \frac{z}{1000} \quad (1)$$

Where,

T_z is the bottom hole temperature at depth Z (m). (4100m for Singra-1 well)

T_o is a mean surface temperature. (35°C in the North)

T_g is the geothermal gradient °C/km. (34.1°C/km)

The bottomhole temperature is approximately 171.4 °C for the considered location which is viable for establishing a binary cycle geothermal power plant

2.1 Design considerations

The geothermal brine reaching the high temperature of the ground at the drilled depth is pumped to the surface at a suitable rate (100kg/s). The binary cycle powerplant consists of the primary underground heat exchanger where the geothermal brine is heated and brought to surface in a secondary heat exchanger to vaporize the working fluid-usually organic substances with lower boiling points.

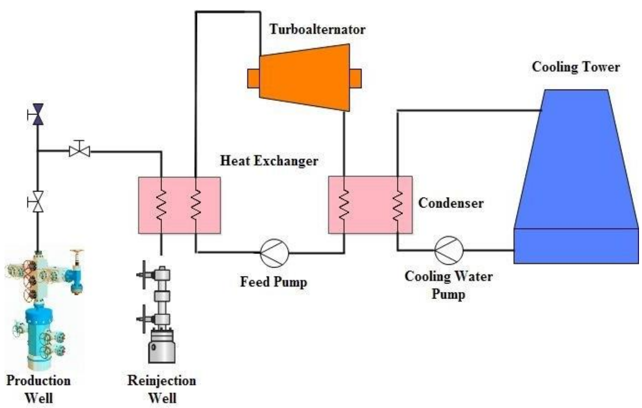

Fig-2: Binary Cycle Power plant Configuration [17]

For an open loop system, a least one production well and one reinjection well is required Among the Singra-1, Singra-2 and Singra-3 well, Singra-1 is chosen as the water producing well for promising temperature record. The reinjection well can be either of the other two wells or a new reinjection well may need to be drilled. For its cheap availability and lower boiling point (11.7 °C) Isobutane is chosen as the working fluid in the secondary heat exchanger.

Table-2: Plant Design assumptions

Parameter	Assumption
Temperature gradient	34.1°C/km
Drilling depth	4 km (Singra-1 well)
Geothermal fluid temperature	T_{geo}=34.1°C/km×4km=136.4°C
Ambient reinjection temperature	30°C
Working fluid	Isobutane (boiling point 11.7°C)
Thermal efficiency	10–12% (ORC cycle)
Mass flow rate of geothermal brine	100 kg/s (for calculation)

Larger well diameters result in higher outlet temperatures and greater power generation because the fluid moves more slowly, allowing more time to absorb heat from the surrounding rock [18]. The water-cooled type condenser is selected for re-injection of water as it has more efficiency in heat rejection than the air-cooled type and water is not scarce in the region. To sustain the required mass flowrate, high efficiency centrifugal pumps are required. As for the turbine type, Binary cycle power plants typically use axial-flow or radial-inflow turbines designed for low-temperature, low-pressure organic working fluids.

2.2 Thermal energy from geothermal fluid

The amount of available geothermal heat depends on the mass flow rate, temperature difference of the geothermal brine as it circulates through the system and system efficiency [19]

$$Q_{in}= \dot{m}.cp.(T_{hot}-T_{cold}) \qquad (2)$$

Where,

$\dot{m}$=100 kg/s

cp (specific heat of water) = 4.18 kJ/kg°C

T_{hot}= T_{geo} = 136.4°C

T_{cold}=30°C

Q_{in}=100 x 4.18 x (136.4−30)
=44,481.92 kW
=44.48 MW

$P_{out}=\eta\cdot Q_{in}$
=0.12 x 44.48 MW
=5.34 MW_{el}

The calculations show that the electric power output from the plant can be up to 5.34 MW.

3. Discussion

3.1. Sensitivity Analysis

For the successful open loop circulation of geothermal fluids, detailed on-site assessment is required. In case the chosen well is not found suitable after on-site assessment, changes in well selection will cause large variation in the quantitative analysis. Heat extraction and enthalpy of the system is dependent on the associated reservoir conditions at depth. In one study on development of a low-enthalpy geothermal reservoir it was found that, due to the reservoir heterogeneity, the flow path varies significantly with local well positioning. In the studied realistic reservoir model, a synchronous minor location shift of both wells by approximately 50 m horizontally leads to a variation of project lifetime of more than 25% [20]. This indicates the necessity to perform an uncertainty analysis of well placement based on detailed geological characterization. If closed loop circulation is considered, single well U-tube system, mono-bore induction technology can be employed [18].

Other assumed parameters for the quantitative analysis conducted in this paper include working fluid type, thermal efficiency of the ORC cycle and mass flow rate of the geothermal brine. The choice of working fluid strongly influences ORC performance. Substituting isobutane with fluids such as n-pentane, R245fa, isopentane or other Rankine cycle fluid could shift the cycle efficiency by several percentage points due to differences in boiling point, specific heat, and expansion ratio. For instance, a 1–2% variation in thermal efficiency could alter the predicted output by 0.45–0.9 MW, influencing both plant capacity and economic feasibility. The fluid flow rate may need to be adjusted depending on tubing pressure, pump capacity, and heat exchanger performance to ensure safe and efficient plant operation.

At a pilot 2.5 MW binary cycle power unit in the Pauzhetskaya geothermal power plant, Kamchatka, an organic refrigerant compound R-134a was selected as the working fluid. Where, at the inlet of the evaporator–superheater, the intake flow rate of the geothermal waste liquid phase is 117.9 kg/s, the pressure is 0.2 MPa, and the temperature is 120°C.[21]. This comparison shows that the choice of working fluid type in the ORC system plays significant role in system efficiency and plant capacity.

3.2. Plant Efficiency

Organic-Rankin-Cycle (ORC) systems use an organic working fluid with a low boiling point to vaporize at these lower temperatures, drive a turbine, and generate power. For low temperatures, economic sustain-ability can be found in the organic Rankine cycle (ORC). The ORCs can convert the enthalpy to work at low and medium temperatures, at 80–85◦C, electricity can be produced when geothermal energy is utilized [22]. There are hundreds of organic fluids available for use in the Organic Rankine Cycle (ORC). ORC technology is a state-of-the-art system where low enthalpy organic fluids (working fluids typically, isobutane, isopentane, R-134a, and ammonia) with low boiling temperatures relative to water, are vaporized by the recovered well water to generate energy. Any changes to these properties can significantly impact the cycle's performance in areas such as thermodynamics, environmental impact, and economics. It is a highly competitive process because selecting a suitable working fluid involves balancing these multiple factors.

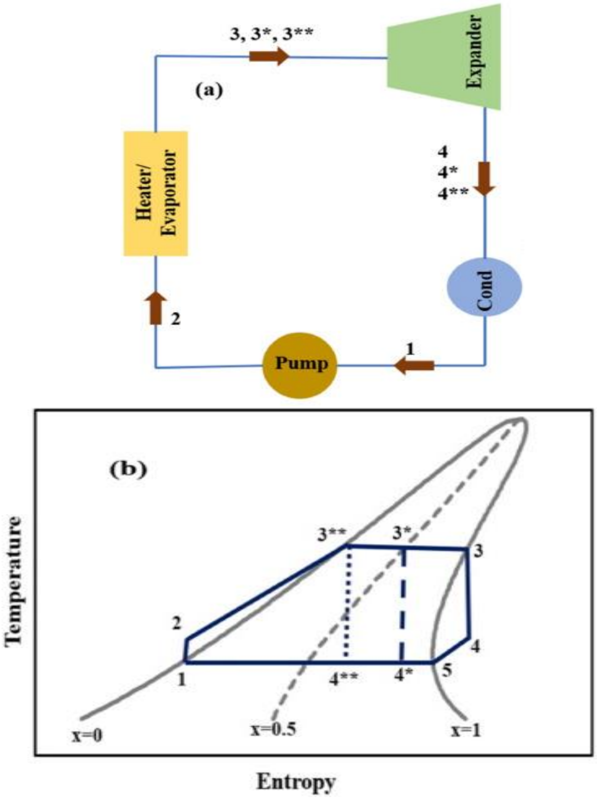

Fig-3: Organic-Rankin Cycle Entropy

Most of the CFC fluids have been banned and organic hydrocarbon fluids are preferred with lower environmental impacts. For its cheap availability and lower boiling point (11.7 °C) Isobutane is chosen as the working fluid in the secondary heat exchanger. The efficiency of the Organic Rankine Cycle (ORC) in a binary geothermal power plant typically ranges from 8% to 20%, depending on factors such as the geothermal fluid temperature, the type of organic working fluid, and system design [23].

In this cycle, heat from a moderate-temperature geothermal source is transferred to the organic fluid (Isobutane) via a heat exchanger. The fluid vaporizes and expands through a turbine, generating mechanical power that is converted to electricity. After expansion, the vapor enters a condenser, where it is cooled and condensed back into a liquid, usually using air or water as a cooling medium. A pump then pressurizes the liquid and recirculates it to complete the cycle. Although the ORC's thermal efficiency is lower than that of conventional steam Rankine cycles, its ability to operate with low-temperature heat sources makes it highly suitable for geothermal applications.

4. Conclusion

A 5.34 MW binary cycle geothermal power plant has the potential to contribute to Bangladesh's national energy goals by providing a reliable and renewable source of electricity. Binary cycle technology is particularly suited for moderate-temperature geothermal resources, such as those found in the northern regions of Bangladesh. Geothermal energy can reduce dependency on fossil fuels, cut greenhouse gas emissions, and enhance energy security. Moreover, the consistent power output from geothermal sources ensures stable electricity supply, which can support industrial development, improve local infrastructure, and provide households with uninterrupted access to electricity.

However, while the technology offers clear advantages, certain design limitations must be considered. Binary cycle plants have relatively high initial capital costs, and their efficiency is constrained by the moderate temperatures of the available geothermal fluids. Careful attention must be paid to heat exchanger design, working fluid selection, and scaling/corrosion management to ensure long-term performance. The plant development can improve the quality of life in northern Bangladesh by creating jobs, supporting rural electrification, and demonstrating the feasibility of renewable energy deployment in the country.

In addition to energy security, the development of a binary cycle geothermal plant can generate broader socio-economic and environmental benefits. Local communities of the north can gain access to clean and reliable power, which improves education, healthcare, and small business opportunities. The plant's low environmental footprint compared to conventional fossil fuel plants helps protect ecosystems while contributing to Bangladesh's commitment to climate action and sustainable development goals. By showcasing the practicality of small-to-medium scale geothermal projects, this initiative can encourage further investment and research in renewable energy, paving the way for a diversified and resilient energy sector in the country.

Repurposing abandoned hydrocarbon wells offers a practical and cost-effective pathway for developing geothermal energy in Bangladesh. Future research should focus on site-specific studies for pilot-scale demonstrations to validate reservoir performance, detailed techno-economic analysis of ORC system optimization and environmental impact assessments**.** Further numerical simulations incorporating transient thermal behavior and reinjection effects would refine the power capacity estimates and support future commercial deployment

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