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# GEOTHERMAL ENERGY APPLICATIONS AS A SUSTAINABLE RENEWABLE SOURCE FOR ABANDONED OIL WELLS

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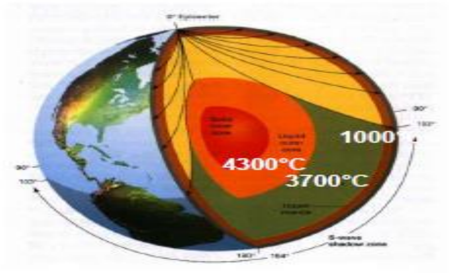
**Abstract:** Earth's natural heat has been used by humans for thousands of years. Based on historical records, it has been used in various parts of the world for medical purposes, cooking, bathing, and space heating. In light of the limited supply of fossil fuels, efforts are being directed toward alternate raw materials. An energy source that originates from the earth's interior heat is called geothermal energy. The two primary ways in which this energy source is utilized directly and indirectly are the cleanest. This research aims to investigate three characteristics, namely well depth, well temperature, and temperature gradient, to expound on the various applications of geothermal energy for ten abandoned oil wells in the Defa oilfield of the Waha oil business. Conversely, geothermal energy is used for a variety of direct uses, such as swimming and bathing, agriculture, aquaculture, industrial processing, ground heat pumps, etc.; and indirect uses, such as electric power plants. Geothermal energy is dependent on the depth and temperature of the geothermal source. It is consistently accessible and works well with other renewable energy sources including hydro, solar, and wind.The findings revealed that the energy ranges from low to high enthalpy and the average temperature value of the produced water is 212.10°C, whereas the flash steam power plants can be used for electricity generation besides the other different applications. The power output according to the different reported authors ranging from 59.4 to 364 kW. The best conventional geothermal resources are localized by favourable geological conditions. The future of geothermal energy is tied to unlocking the vast source potential lying at deeper levels and across much larger using Enhanced Geothermal System (EGS) technology.

**Keywords**: Geothermal energy, direct application, indirect application, aquaculture, agriculture, ground source heat pump, power plant.

## 1. Introduction

The Earth's interior provides the geothermal energy, which is heat. Buildings can be heated or electricity can be produced by recovering this heat as steam or hot water. The continuous production of heat within the Earth makes geothermal energy a renewable energy source (Figure 1). The European Union defines geothermal energy as "heat stored beneath the surface of solid Earth" (Blodgett and Slack, 2009). It is possible to replenish geothermal energy. There is always geothermal energy available, unlike solar and wind energy, which is more reliant on climatic variations and weather patterns. Earth's heat is produced by geothermal energy. The hydrothermal system is a classification for geothermal systems with medium or high temperatures.




Internal Earth structure

Geothermal flow


**Fig. 1:** Earth's temperatures and geothermal types (Blodgett and Slack, 2009)

### 1.1. Earth's Heat Sources

Earth's heat sources are including:

1. Residual heat of the Earth interior (mantle and core). Figure 2 gives Earth's temperatures, while Figure 3 gives an example of geothermal energy.
2. Decay of radioactive isotopes: U238, U235, Th232, K40 (crust).
3. Solar radiation (limited 5-25 m below the ground).

- Internal heat production: 20TW
- Measured heat flow Qs = 44TW (Blodgett and Slack, 2009)

Figure 2 show the different types of geothermal energy and some their applications.

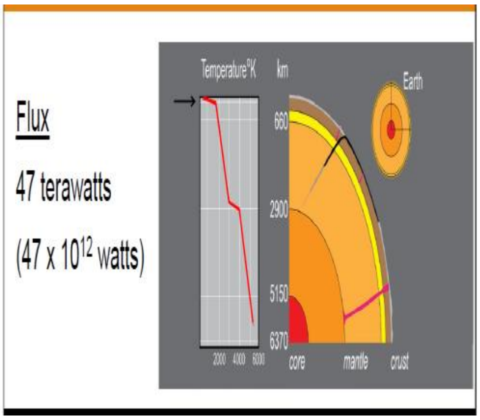



**Fig. 2:** Earth's heat (Boehler, 1996; Ritter, 1999)

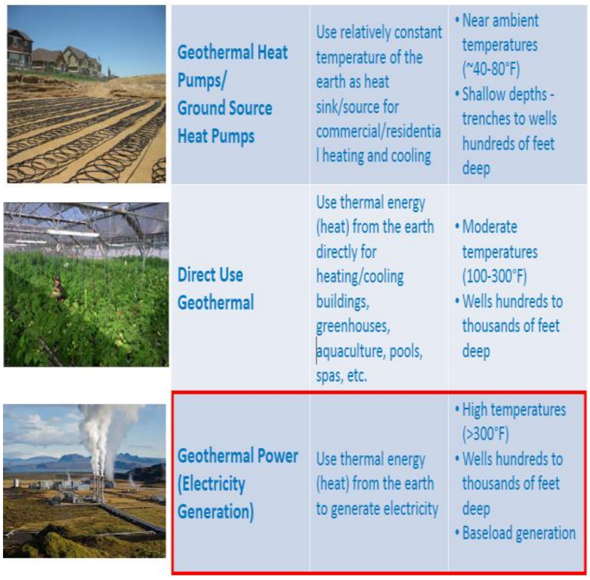



**Fig. 3:** Geothermal energy types and their uses (IEA, 2021)

### 1.2. Where Geothermal Energies Occurs

Geothermal reservoirs are naturally occurring, sizable areas of hydrothermal resources. The "ring of fire," or active geothermal zones found throughout the world, is depicted in Figure 4. There are instances when geothermal energy rises to the surface as:

1. Fumaroles, or holes where volcanic gases are released, and volcanoes
2. Warm springs
3. Water jets


**Fig. 4:** A map showing the locations of volcanic activity in the Pacific National Energy Education Development Project is the source (Public Domain).

### 1.3. STUDY OBJECTIVES

Here are some categories in which the study's goals can be placed:

1. To look into the possibility of using geothermal energy as a renewable energy supply.

2. To recognize that this energy source is good and wonderful options because it is limitless.

3. To identify the different utilizations and applications.

### 1.4. STUDY METHODOLOGY

The information was gathered from four separate authors' geothermic publications (Lund and Freeston, 2001; Lund et al., 2005; Lund et al., 2011; Lund, J. W., Boyd, 2016; Lund et al., 2020; European Geothermal Congress, 2007; 2013; 2019) as well as from country update reports from previous World Geothermal Congresses.

This paper describes the methodology which can be followed to evaluate the possibilities and the using of geothermal and its utilizations for various applications through ten abandoned oil wells at Defa oilfield of Al Waha Oil Company (Waha-59).

## 2. GEOTHERMAL RESOURCES CLASSIFICATION

The average reservoir temperature can be used to categorize geothermal resources into low, intermediate, and high enthalpy sources (Table 1). Various authors have divided the classes of resources shown in Table 1 in a subjective manner. Regarding which temperature ranges are suitable to characterize each class of geothermal resource, the cited authors cannot agree.

**Table 1:** Classification of geothermal resources (°C)

| Resource | Muffler & Cataldi, 1978 | Hochstein, 1990 | Benderitter & Cormy, 1990 | Haenel, 1988, Dickson, 1990 | Nicholson, 1993 | Axelsson, 2000 |
|---|---|---|---|---|---|---|
| Low enthalpy | <90°C | <125°C | <100°C | ≤150°C | ≤150°C | ≤190°C |
| Intermediate enthalpy | 90-150°C | 125-225°C | 100-200°C | --- | -- | -- |
| High enthalpy | >150°C | >225°C | >200°C | >150°C | >150°C | >190°C |

The state of geothermal fluids cannot be accurately described by temperature and enthalpy alone. Nevertheless, based on the reservoir fluid temperature (Figure 5; Muffler and Cataldi, 1978; Sanyal, 2010; Rybach, 2010), geothermal resources are categorized as high-enthalpy fields (temperature is>150˚C), medium-enthalpy fields (temperature is 90˚C to 150˚C), and low-enthalpy fields (temperature is< 90˚C).

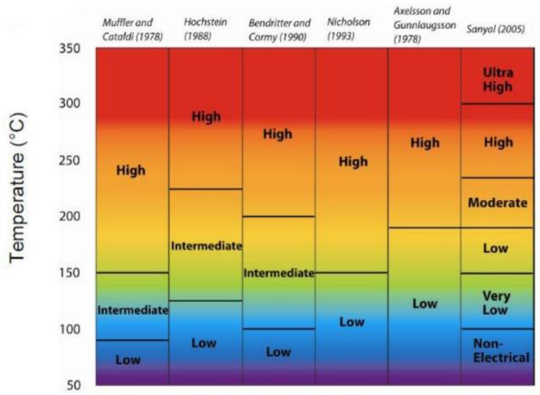



**Fig. 5:** Classification of geothermal resources Temperature/Enthalpy

Figure 6 depicts the various types of geothermal resources and their applications, also gives the global average geothermal gradient (Moor and Simmons, 2013).

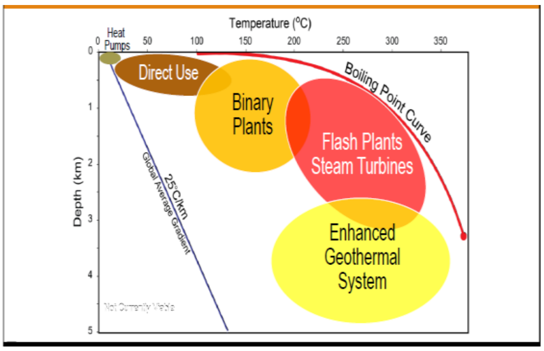



**Fig. 6:** Geothermal resources (Moor and Simmons, 2013; Limberger *et al.*, 2018 and Richter, 2020a)

Younger (2015) gives a proposal for the categorization of geothermal resources according to their pressure, temperature and enthalpy, as shown in Figure 7.

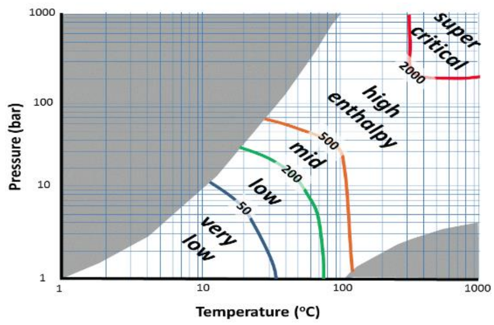



**Fig. 7:** Categorization of geothermal resources. The number on the lines is approximate values of enthalpy in kJ/kg (Younger, 2015)

## 3. GEOTHERMAL SYSTEM

What exactly is a geothermal system and how does it operate? "Convicting water in the upper crust of the Earth, which, in a confined space, transfers heat from a heat source to a heat sink, usually the free surface," is how it is best explained schematically (Hochstein, 1990). Three primary components comprise a geothermal system: a reservoir, a heat source, and a fluid that acts as a heat carrier. One possible source of heat is a magmatic intrusion that has reached relatively shallow depths (5–10 km) but has a temperature far above 600 °C. The heated permeable rocks serve as the reservoir, where heat is extracted by the circulating fluids. The liquid or vapour phase of water, often meteoric water, depending on its temperature and pressure, is the geothermal fluid. Chemicals and gasses like CO2, H2S, and others are frequently carried by this water. An ideal geothermal system is depicted simply in Figure 9.

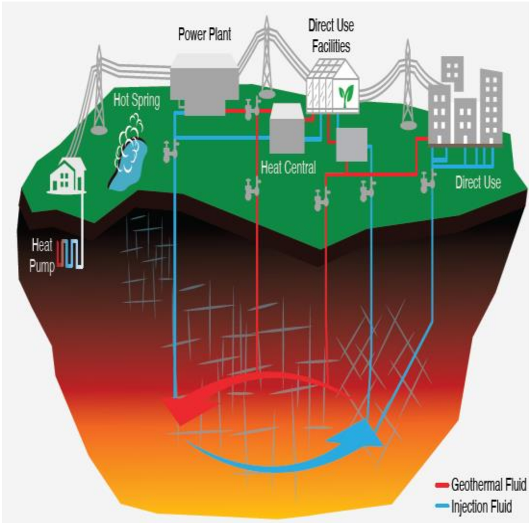



**Fig. 8:** Schematic representation of an ideal geothermal system (Hochstein, 1990)

## 4. APPLICATIONS OF GEOTHERMAL ENERGY

While some geothermal energy uses involve drilling kilometers below the Earth, others make use of the temperatures close to the surface. Geothermal energy is mostly used for three purposes:

1. Hot water from springs or surface reservoirs is used in district heating systems and direct use systems.

2. Power plants that generate electricity need steam or water at temperatures between 300° and 700°F.

3. To regulate building temperatures above ground, geothermal heat pumps take use of steady ground or water temperatures close to the surface of the Earth.

Figure 9 provides a more thorough explanation of the many applications for geothermal fluids and steam based on their temperature range.

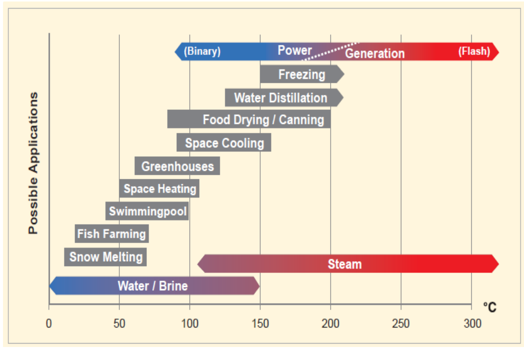



**Fig. 9:** Modified Lindal Diagram Showing Applications for Geothermal Fluids (Lindal, 1973)

### 4.1. Geothermal Energy Direct Use

Since ancient times, hot water has been directly utilized as a source of energy. Hot mineral springs were utilized for heating, cooking, and bathing by the ancient Chinese, Native American, and Roman societies. Many people still take baths in hot springs today because they think the mineral-rich, heated waters have medicinal properties. The direct use of geothermal energy includes a wide range of uses, some of which are illustrated in Figure 10 (Axelsson, et al., 2001; Stefansson and Axelsson, 2003). These uses include space and district heating, swimming pools and balneotherapy, aquaculture, agriculture, and other industrial activities.

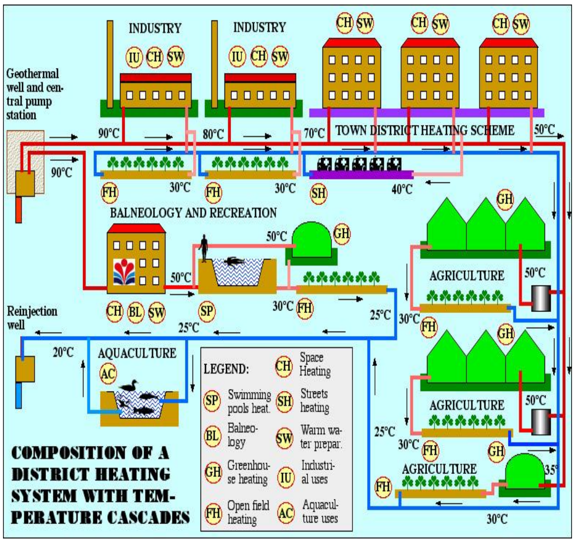


**Fig. 10:** Multiple applications of geothermal energy (Stefansson & Axelsson, 2003)

Geothermal energy's main benefits may be summed up as follows:

1. Low cost of produced power for heating homes and businesses.
2. Minimal contamination of the atmosphere.
3. the most capacity factor available for natural energy sources.
4. Recoverable and with little land usage.
5. it's an indigenous resource.
6. Long-term fuel price variations have little effect on geothermal plants.
7. Better living conditions, cleanliness, and public health.

**4.1.1. Agriculture Using Geothermal Energy**

Heat may be produced directly from geothermal energy, that is, without the need for further conversion. Direct usage is the application of geothermal heat directly onto a surface.

Energy is needed in agriculture at every stage of the food production process: from primary production to postharvest and storage, processing, retail, preparation, and cooking (FAO, 2015, and adapted from Lindal, 1973).

**4.1.2 Heating of Greenhouses**

During the last 25 years, geothermal energy has been used most extensively in agriculture for greenhouse heating. Heating of greenhouses is one of the most common direct applications of geothermal energy, which also controls the climate, primarily relative humidity and temperature. Since different plants and vegetables require different temperatures to grow well, different vegetables (Figure 11) and plants require different temperatures, so the water supplied in greenhouses has to be heated between 40 and 1000C (Vasilevska, 2007).

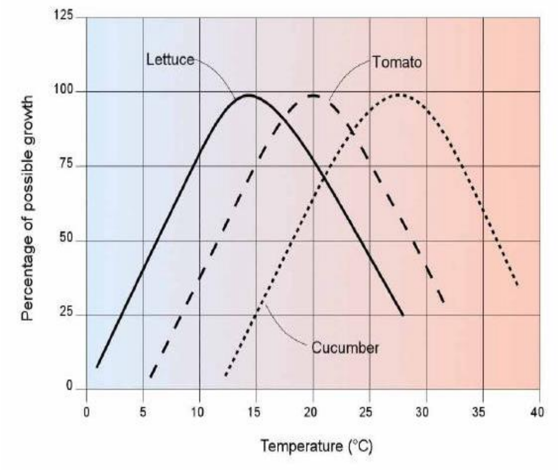



**Fig. 11:** Optimum temperature for growing various vegetables (From Beall and Samuels, 1971)

The greenhouse's walls may be composed of plastic film, glass, fiberglass, or hard plastic panels. Although glass panels are more costly and heavier than plastic panels, they are more transparent and will allow in significantly more light. However, they will also offer less heat insulation and shock resistance. (Figure 12) However, Figure 13 provides an illustration of a greenhouse's application.

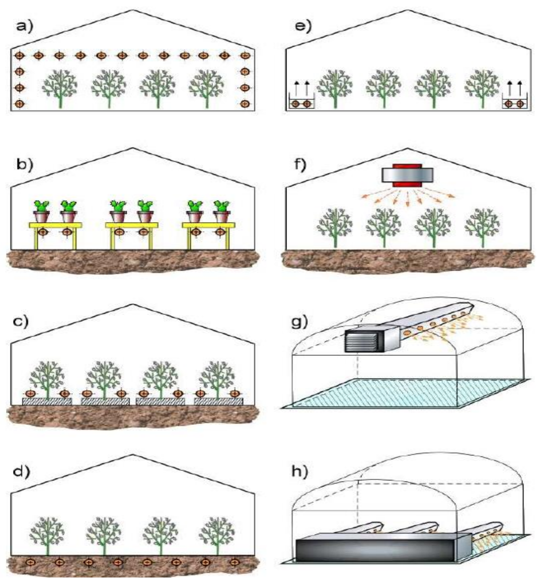



**Fig. 12:** Heating systems in geothermal greenhouses

Heating installations with natural air movement ((natural convection): (a) aerial pipe heating; (b) bench heating; (c) lowposition heating pipes for aerial heating. (d) Soil heating. Heating installations with forced air movement (forced convection): (e) lateral position ;( f) aerial fan; (g) highposition ducts; (h) low-position ducts (From von Zabeltitz, 1986).

**Fig. 13:** Examples of greenhouse geothermal uses for vegetables & fruits crops (von Zabeltitz, 1986).

#### 4.1.3. Aquaculture

Within very tiny temperature differences, fish species exhibit varying rates of growth and production (Johnson, 1981). On the other hand, Figure 14 illustrates how temperature affects the development or yield of food animals.

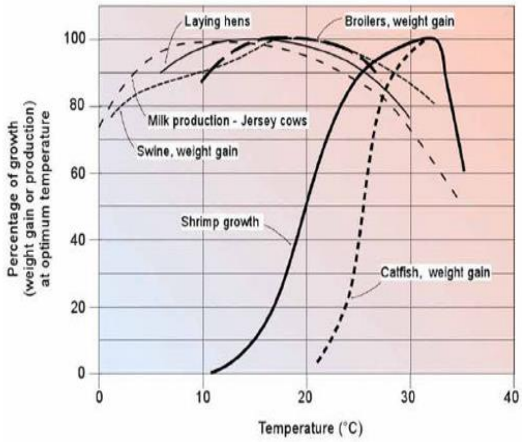



**Fig. 14:** Effect of temperature on growth or production of food animals (From Beall and Samuels, 1971)

#### 4.1.4. Soil Warming

Using geothermal water to warm the soil is a promising technology in agriculture that can boost crop yields. Studies conducted at several locations across the globe have revealed that if the soil temperature is kept at 70°F, some vegetables previously deemed "cool weather" crops as well as some fast-growing trees will grow bigger and quicker.

#### 4.1.5. Balneological and Antibacterial Uses

Balneology is a therapeutic technique used in health spas and hot springs to relieve painful muscles (Figure 15). Therefore, it can be applied to the treatment of hurting muscles as well as skin conditions. This would provide skin disease treatments that are somewhat medical. Recreational activities are beneficial at health spas.


**Fig. 15:** Outdoor swimming pool in Reykjavík Iceland during winter season. Geothermal hot water provides the heating of the pavement (Axelsson, et al., 2001)

**4.2. Industrial Uses**

Including the following applications:

**4.2.1. Potato Processing**

The use of geothermal energy in the food processing, crop drying, and forest-related industries has been thoroughly researched.

**4.2.2. Crop Drying**

The Geothermal energy has been applied in drying of vegetables, fruits crops and other cereals (Lund et. al., 2005) as shown on Figure 16.

**Fig. 16:** Tomatoes loaded on drying racks

**4.2.3. Biogas Generation**

Making biogas is yet another agricultural procedure that needs heat. In essence, it is the process known as anaerobic fermentation the breakdown of organic materials in the absence of oxygen.

**4.3. Ground Source Heat Pump (GSHP) System**

Ground Source Heat Pumps, or GHPs, are one of the renewable energy applications with the quickest rate of growth in the globe (Lund and Freeston, 2000, Lund et al., 2004). Numerous reviews of the literature have been published about ground source heat pump (GSHP) systems, primarily focusing on the general closed loop GSHP system or the U-tube ground type system (Deerman and Kavanaugh, 1991; Yavuzturk et al, 1999). Around 80 years ago, the commercial manufacture of ground-source heat pump systems (GSHP) was initiated, with a capacity of 100 megawatts, catering to both direct use and energy generation applications

(Fridleifsson, 2001). Two categories comprise the GSHP system (Ayling, 2007b):
(1) Closed Loop System: This system consists of the lake/pond, vertical, and horizontal components. Open Loop System (2)

### 4.4. Geothermal Power Plants

Three types of geothermal power plants use turbines and electric generators to convert the earth's heat into electricity:

#### 4.4.1. Flash Steam

Flash steam technology is used in the most prevalent kind of geothermal power plant. When subterranean water that has reached temperatures above 360°F is sprayed into a tank that is kept at a pressure significantly lower than the water, part of the water vaporizes, or "flashes." To create energy, a turbine is turned by this vapor (Figure 17).

#### 4.4.2. Dry Steam

This steam is pumped directly to a turbine to power an electric generator (Figure 17).

#### 4.4.3. Binary Cycle

Geothermal water with a modest temperature range (200–300°F) is used in binary cycle plants. A heat exchanger is used to transmit both this hot geothermal water and a liquid with a lower boiling point. After that, the fluid with the lower boiling point turns to vapor and drives a turbine (Figure 17).

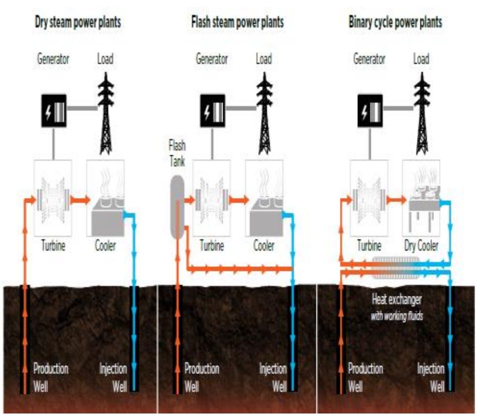



**Fig. 17:** Geothermal power-plant configurations: dry steam, flash steam, and binary cycle (modified after Ayling, 2007b)

## 5. ABANDONED OIL WELLS FOR GEOTHERMAL ENERGY

When drilling a dry hole occurs or the oil/gas reservoir becomes unusable for petroleum production, petroleum well is abandoned. Even after being sealed with cement and shut off, abandoned wells continue to pose a financial and environmental risk. Drilling wells to access resources with greater temperatures has a significant financial expense, which is the primary drawback of using deep geothermal resources for energy extraction. Yet, there's a fascinating chance to save the upfront expenses of drilling by using abandoned oil wells.

### 5.1. Case Study

#### 5.1.1. Geothermal Energy Production from Abandoned Oil Wells

Petroleum wells are often deep enough to reach high temperature strata, making retrofitting abandoned wells for geothermal extraction a unique concept (EIA, 2012). As the world's largest oil and gas drilling country, the US has dug more than 2.5 million petroleum wells since the 1950s (Baker Hughes, 2012).

#### 5.1.2. Study Location

This study was performed on ten abandoned oil wells at Defa oilfield of Al Waha Oil Company (Waha-59) as shown in Figure 18, to assess the potentiality of geothermal extraction as presented in Table 2. These wells exhibit a variation for their depths, fluid production, pressure, temperature and temperature gradient.

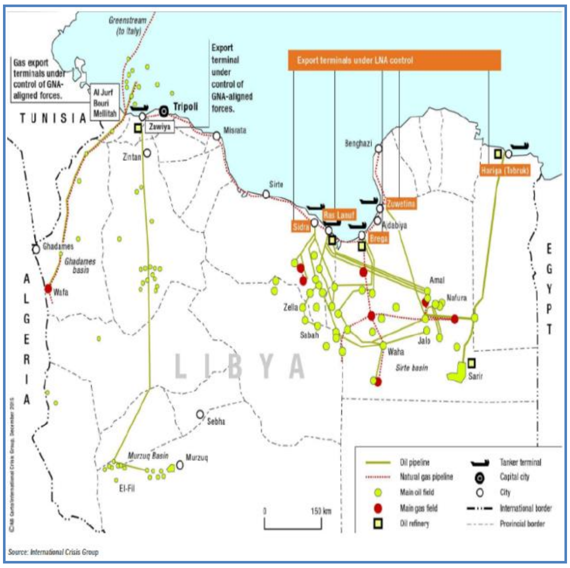



**Fig. 18:** Major oil and gas fields and infrastructure in Libya (Source: International Crisis Group, APICORP; 2018)

### 6. RESULTS AND Discussion

This study aims to examine the oil wells that have been investigated for the generation of geothermal energy and to determine what kinds of applications and utilizations are possible. As a result, the temperature of the borehole determines how geothermal energy is classified; the outcomes are shown in Table 2. The studied wells can be used for a wide range of applications because of their high temperature sources, which range from 188°C (B-X8-59W) to 235°C (B-X3-59W), with an average value of 212.10°C (Table 2). Lindal (1973) describes the various applications of geothermal fluids as a function of their temperature, modified after ORC denotes the Organic Rankine Cycle. These applications include heat generating and heat pumps, as well as conventional and ORC or Kallina Cycle power generation.

### 6.1. Geothermal Resources Classification

The geothermal resources can be categorized by temperature into several enthalpies, as shown in Table 3, according to the cited authors (Muffler & Cataldi, 1978; Hochstein, 990; Benderitter & Cormy, 1990; Haenel, 1988).

**Table 2:** Abandoned oil wells at Defa oilfield

| No. | Abandoned oil wells | Depth (ft) | Pressure (psia) | Fluid production, Q (bb/d) | Fluid temperature (℃) | Temperature gradient (°C/100 m) |
|---|---|---|---|---|---|---|
| 1 | B-X1-59W | 7700 | 2550 | 1550 | 210 | 3.72 |
| 2 | B-X2-59W | 7990 | 3052 | 1900 | 218 | 3.77 |
| 3 | B-X3-59W | 8985 | 3599 | 1492 | 235 | 3.81 |
| 4 | B-X4-59W | 9320 | 3950 | 1100 | 220 | 3.87 |
| 5 | B-X5-59W | 10200 | 4690 | 2620 | 216 | 3.99 |
| 6 | B-X6-59W | 9759 | 4435 | 1190 | 202 | 3.88 |
| 7 | B-X7-59W | 9980 | 3380 | 5040 | 210 | 3.81 |
| 8 | B-X8-59W | 7999 | 4382 | 3770 | 188 | 3.69 |
| 9 | B-X9-59W | 8780 | 3490 | 8900 | 190 | 3.78 |
| 10 | B-X10-59W | 10285 | 4250 | 1590 | 232 | 3.98 |
| | $\bar{x}$ | 9099.8 | 3777.80 | 2915.2 | 212.10 | 3.83 |

**Table 3:** Classification of geothermal resources by temperature of investigated wells

| Abandoned oil wells | Fluid temperature (℃) | (A) | (B) | (C) | (D) | (E) | (F) |
|---|---|---|---|---|---|---|---|
| B-X1-59W | 210 | H. E. | L. E. | H. E. | H. E. | H. E. | H. E. |
| B-X2-59W | 218 | H. E. | L. E. | H. E. | H. E. | H. E. | H. E. |
| B-X3-59W | 235 | H. E. | H. E | H. E. | H. E. | H. E. | H. E. |
| B-X4-59W | 220 | H. E. | L. E. | I. E. | H. E. | H. E. | H. E. |
| B-X5-59W | 216 | H. E. | L. E. | H. E. | H. E. | H. E. | H. E. |
| B-X6-59W | 202 | H. E. | I. E. | H. E. | H. E. | H. E. | H. E. |
| B-X7-59W | 210 | H. E. | L. E. | I. E. | H. E. | H. E. | H. E. |
| B-X8-59W | 188 | H. E. | L. E. | I. E. | H. E. | H. E. | H. E. |
| B-X9-59W | 190 | H. E. | L. E. | I. E. | H. E. | H. E. | H. E. |
| B-X10-59W | 232 | H. E. | H. E | H. E. | H. E. | H. E. | H. E. |
| Legend<br>L. E. = Low enthalpy<br>I. E. = Intermediate enthalpy<br>H. E. = High enthalpy | | | | References<br>(A) = Muffler & Cataldi, 1978<br>(B) = Hochstein, 1990 | | | |

| | |
|---|---|
| | (C) = Benderitter & Cormy, 1990<br>(D) = Haenel, 1988, Dickson, 1990<br>(E) = Nicholson, 1993<br>(F) = Axelsson, 2000 |

**6.2. Flash Steam Power Plants**

Reach into water reservoirs that are hotter than 180°C. Some of the heated water boils or "flashes" into steam when the fluid pressure drops while it moves. After being separated at the surface, the steam powers a turbine/generator device. Hence the average temperature value of the produced water is 212.10°C the flash steam power plants can be used for electricity generation besides the other different applications.

**6.3. Geothermal Gradient**

Based on the assessments of international experience, Table 4 was created. The produced power value as a function of well depth and geothermal gradient strength is displayed in the table.

**Table 4:** Geothermal gradient impact on the output power

| Authors | Power output, kW | Well depth, ft | Geothermal gradient, °C/km |
|---|---|---|---|
| Kujawa et al. (2006) | 140 | 3950 | 25 |
| Bu et al. (2014) | 59.4 | 4000 | 38 |
| Cheng et al. (2014) | 239 | 6000 | 50 |
| Noorollahi et al. (2015) | 133 | 3861 | 29.6 |
| | 364 | 4423 | 31.2 |
| Wight and Bennett, (2015) | 217 | 6000 | 50 |

Table 4 makes it evident that while depth has less of an impact, more electricity may be produced the greater the geothermal gradient value. Conversely, Table 5 reports the output power depending on the geothermal gradient of the wells under study, as reported by the authors Kujawa et al. (2006); Bu et al. (2014); Cheng et al. (2014); Noorollahi et al. (2015), and Noorollahi et al. (2015). On the other hand, some writers claim that the output power ranges from 59.4 to 364 kW.

**Table 5:** Output power based on geothermal gradient of studied wells

| No. | Abandoned oil wells | Depth (ft) | Temperature gradient (°C/100 m) | Authors | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Kujawa et al. | Bu et al. | Cheng et al. | Noorollahi et al. | |
| | | | | Power output, kW | | | | |
| 1 | B-X1-59W | 7700 | 3.72 | 140 | 59.4 | --- | 364 | 364 |
| 2 | B-X2-59W | 7990 | 3.77 | 140 | --- | --- | 364 | 364 |
| 3 | B-X3-59W | 8985 | 3.81 | 140 | --- | --- | 364 | 364 |
| 4 | B-X4-59W | 9320 | 3.87 | 140 | 59.4 | --- | 364 | 364 |
| 5 | B-X5-59W | 10200 | 3.99 | 140 | 59.4 | --- | 364 | 364 |
| 6 | B-X6-59W | 9759 | 3.88 | 140 | 59.4 | --- | 364 | 364 |
| 7 | B-X7-59W | 9980 | 3.81 | 140 | --- | --- | 364 | 364 |
| 8 | B-X8-59W | 7999 | 3.69 | 140 | --- | --- | 364 | 364 |
| 9 | B-X9-59W | 8780 | 3.78 | 140 | --- | --- | 364 | 364 |
| 10 | GX10 | 10285 | 3.98 | 140 | 59.4 | --- | 364 | 364 |

Figure 19 shows the temperature versus depth correlation for the investigated oil wells. It is obviously that is a linear relationship between the two variables.

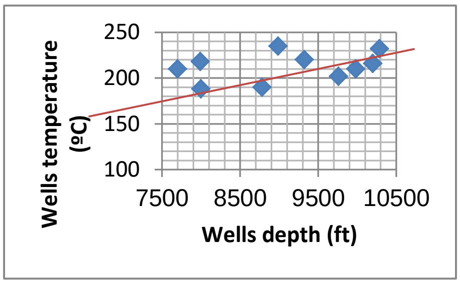



**Fig. 19:** Temperature versus depth of investigated abandoned wells

## 7. Conclusions

In light of previous study the following conclusion can be drawn:

1. Increasing interest in "green" and "renewable" energy sources.
2. Geothermal energy is a renewable source.
3. It is used for various applications in two ways e.g. direct and indirect utilizations.
4. It is clean, always available; it complements wind, solar and hydro generation.
5. The best resources are localized by favourable geological conditions.
6. New EGS technologies are required to unlock the large resource potential.
7. Geothermal direct-use is in main cases replacing fossil fuels and thus reducing greenhouse gas emissions
8. Geothermal can make a major contribution to the world energy needs
9. Geothermal heat pumps are the fastest growing direct use of geothermal energy –available anywhere for heating and cooling.
10. The obtained results revealed that the geothermal energy of the investigated oil well can be classified into low, intermediate and high enthalpy.
11. The output power according to different authors ranging from 59.4 to 364 kW
12. However, "geothermal" is not well known and the benefits generally unknown–it needs to be promoted better.

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