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A Review of the Geothermal Potential Hot Spots in Iraq Using Geophysics Methods

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Abstract

This review introduces the concept of geothermal energy and the technologies used to harvest this sustainable and clean source. Geothermal systems were explained in details in the review. They were classified into two major types, steam cycle and binary cycle. The steam cycle is always used at higher enthalpy, and a binary cycle is used at low enthalpy. The power generation methods used to produce geothermal power from geothermal resources, typically, comprises of well production, injection and steam and gas separators, heat exchangers, preheaters, turbines and condenser. The steam cycle type allows the water to evaporate and the steam will be separated from brine solution and expanded in a turbine, generally the salty water will have discarded out of system, or it is flashed again at lower system part. Power generation methods were divided into single Flash Steam Plant, Double Flash Steam Plant, and Dry Steam Plant. The components of the geothermal power plant were elucidated, namely, feed pump, heat exchanger, preheater, evaporator, turbine, and condenser. After surveying the geothermal energy worldwide briefly, the Iraqi geothermal energy was introduced. Thermal gradient in Iraqi tectonic zone was analyzed. There is a very limited available literature on Iraq geothermal. However, we were able to analyze the geothermal temperature gradient in Iraq by dividing it into two regions; the northern Iraq, and the southern Iraq. Our analysis shows that Iraq is a poor zone for geothermal with no significant hot spots all over the country. However, low temperature applications can be invested using the exhausted petroleum wells.

Keywords: Geothermal Energy, Hot Spots in Iraq, Renewable Energy, Well Drilling, Hydrothermal.

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1. Introduction

Geothermal energy is a clean and sustainable source of renewable energy that has been used since 120 years ago [1]. Today, there are more than 20 countries worldwide that are using geothermal energy with a total power of 13.3GW by the end of 2018 [2]. Geothermal energy can be used in greenhouse heating (low temperature), or in refrigeration, air conditioning and power generation (high temperature) [1].

Geothermal electric power is produced by digging wells deep to the hot Earth's crust then pumping water to obtain steam that drives turbines to generate electricity. Historically, the very first geothermal plant was established in Tuscany – Italy in 1903, where Lardorello dry stream field based generator was installed. This very first plant produced only 10kW of power [3]. Lardorello is now more than 34 plants that produce 800MW of electric power [3].

Geothermal energy is a combination of the remaining heat in the Earth's core during the Earth formation and the decay of the radioactive isotopes of heavy nuclei in the core [4]. Geothermal energy can be found in a form of (i) volcanos, (ii) hot springs, or (iii) geysers [5]. The so-called "Ring of Fire" is an area in the Pacific Ocean that has 75% of the world's active volcanos. Therefore, there are more than 300 hot springs in India [5]. At the core, rocks melt due to high temperature and pressure creating magma. Magma moves upward because of its relative high viscosity and heats rocks and water in the crust [1]. The core temperature is about 6650 °C, while the crust temperature just below the surface can reach up to 2200 °C. The temperature gradient as a function of depth is roughly a constant value 17°C / 1km of depth. However, in some regions that associated with tectonic activities, the temperature gradient is much higher than normal, for instance, the gradient in Lardorello – Italy, is 30 °C for each 100 m of depth (ten times higher than normal regions). This means that 300 °C can be reached at 1 km depth [1]. This temperature gradient can be considered an economically viable, where drilling to this depth is technologically available in reasonable cost. In these hot spots, fluid is existed in reservoirs which is mixture water, minerals, and dissolved gas. The technology is designed to pull this mixture into the surface, treat it to generate electricity, then returning it through injection wells.

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Iraq faces a serious challenge in the production and distribution of electricity. Economic and powerful methods are necessary to find a permanent solution. Renewable energy should be considered as one of the solutions. Various renewable sources are widely investigated in Iraq [6], [7]. However, geothermal energy is poorly covered [8]. This review investigates the hot spots tectonics in the Iraq region.

2. Geothermal Power Plant Technologies

Most power generation plants are based on steam technology where steam rotates turbines to generate electricity. Hydrothermal is a major type of geothermal energy resource that is used in geothermal power plants [9]. The intended system is discordant in two styles, those are vapor dominated and water dominated [10].

Vapor-dominated style merits at high temperature value with a system efficiency range of about 50-70% [9], [11]. Flash steam power plant generally uses water–dominated system in both types (single stage and multi stage cycles) [9], [12]. Multi stage system is eligible to produce power of 15-20 % more than single stage cycle when put in same conditions [13]. However, the binary power plants that utilize low boiling fluids are more appropriate to anticipate these situations for geothermal power plant [1]. In most cases hot pressurized water will be the fluid, if the reservoir is close to the surface, hot water will remain such even when a well is drilled and the reservoir is put at the atmospheric pressure. This is the case of low enthalpy geothermal resources which are available in larger scale than high enthalpy fluids.

The new energy concept is to reduce greenhouse gases effect and minimize fossil fuel fluctuations demands, to achieve increasing the renewable energy resources and to modify power efficiency. The new European parliament policy 20-20-20 could be required to apply in euro region to reduce harmful gases emission about 20%, boost renewable energy 20%, and to increment power efficiency 20%. There are several power generation methods that are used to produce geothermal power from geothermal resources. Typically, it comprises of well production, injection and steam and gas separators, heat exchangers, preheaters, turbines and condenser.

The designs of geothermal power plant become involved in one of four denominations: single flash, double flash, dry steam, and binary. The system design in most cases is a

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function of the available geothermal resources temperatures and pressures [13]. Geothermal systems can be classified into two major types, steam cycle and binary cycle. The steam cycle is always used at higher enthalpy, and a binary cycle is used at low enthalpy. The steam cycle type allows the water to evaporate and the steam will be separated from brine solution and expanded in a turbine, generally the salty water will have discarded out of system, or it is flashed again at lower system part. A single flash type (SF) is shown in Figure (1), and the double flash (DF) is shown in Figure (2).

A secondary heating medium in closed generating cycle is used in a binary cycle, so that heat exchanger will absorb the heat from hot brine fluid to the heating medium, and cooled brine, and pressurize it again to the well. The Organic Rankin Cycle (ORC) and Kalina cycle are used for geothermal energy resources in medium temperature ranges [12].

2.1. Single Flash Steam Power Generation

As shown in Figure (1), the geothermal fluid enters to the well by injection pump. The fluid starts to boil at the bottom stage of the well due to well pressure loss, and then goes upside the well. The well produce admixture of steam and boiling liquid. The single flash power generating system is comparatively non complicated style for converting a thermal power. A separator is part of general scheme of the plant and there are a lot of possible designs. The separated liquid will be injected to the well again after separation of hot liquid and vapor inside the separator, and the separated steam directly enters to the turbine. Figure (2) represents a single flash steam cycle schematic graph [14].

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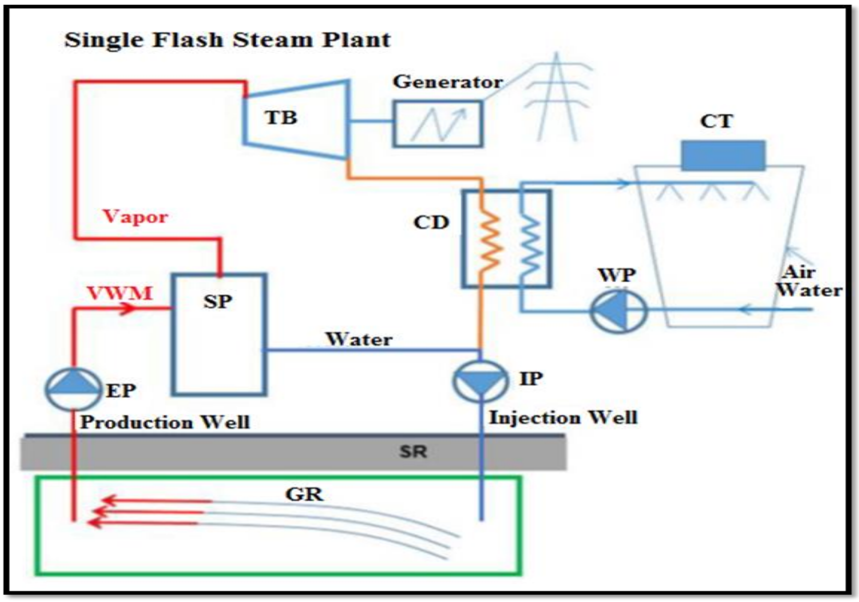

Fig. (1): Single Flash Steam Plant. (TB: Turbine, CD: Condenser, WP: Cooling Water Pump, CT: Cooling Tower, EP: Extraction Pump, IP: Injection Pump, SP: Separator, GR: Geothermal Reservoir, and VWM: Vapor Water Mix.)

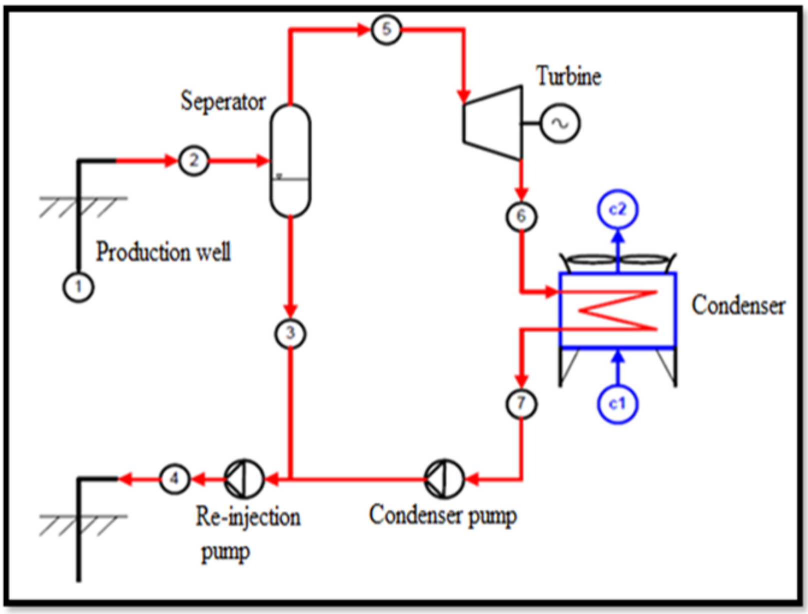

Fig. (2): Single Flash Cycle Scheme.

2.2. Double flash steam power generation

It also built up at high temperature resource. This type of power generation is a modification of a single flash style. It can produce (12-24)% output power more than

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of some geothermal fluid techniques. This type is complicated, higher cost and requires extra embalmment fee, but can increase the potential of generating source. The fundamental feature of this style is the separation of liquids will be used to produce additional steam vapor at lower possible pressure, separated vapor and the additional steam will enter the turbine inlet and produce power.

The brine solution exits from a production well as a saturated vapor above the atmospheric pressure, passing through a throttle nozzle. The brine solution enters the separator, where saturated vapor will be sent to a high pressure turbine. The saturated liquid passes from the separator through a second throttle nozzle and produces lower pressure saturated vapor to combine with the exhaust of high pressure turbine and low pressure turbine are used to generate electrical power from generator. The turbine exhaust is condensed in a condenser, through cooling tower device. The saturated liquid exiting the separator and re-injected into well by injection well pump. A schematic diagram of double-flash geothermal power plant is shown in Figure (4).

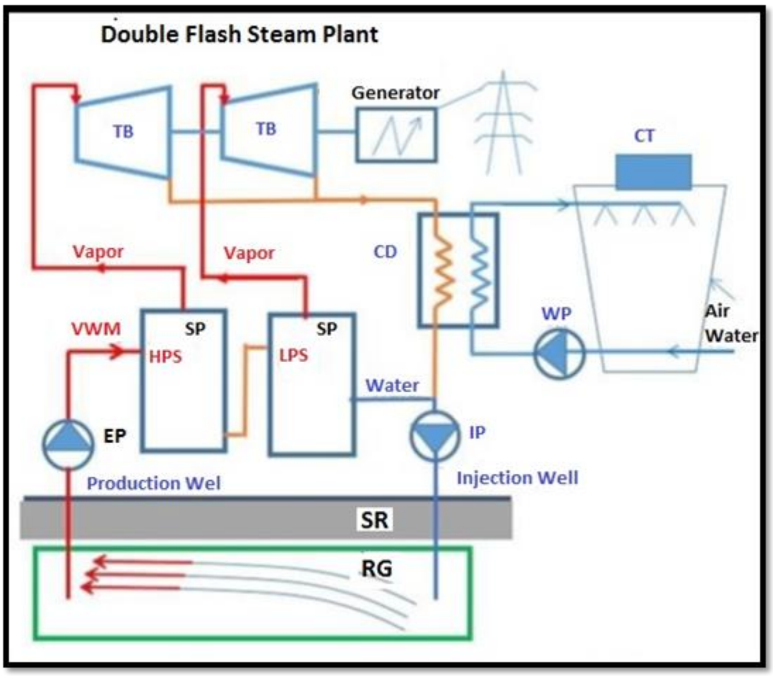

Fig. (3): Double Flash Steam Plant. (TB: Turbine, CD: Condenser, WP: Cooling Water Pump, CT: Cooling Tower, EP: Extraction Pump, IP: Injection Pump, SP: Separator, GR: Geothermal Reservoir, VWM: Vapor Water Mix, HPS: High Pressure Steam, and LPS: Low Pressure Steam.)

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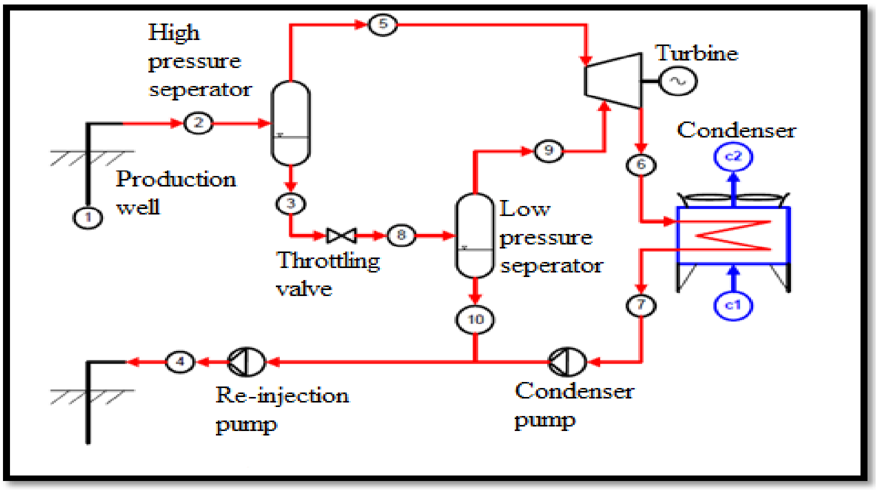

Fig. (4): Double flash cycle scheme.

2.3. Dry Steam Generation

The simplest configuration with comparable devices to a flash plant called dry steam geothermal plant, but the separator and two phase pipelines were insulated. However, dry steam fields are pickled geothermal manifestation, as only a few of such hydrothermal systems have been come cross on world till yet. This technique was first used for power production. However, the geothermal wells eject an admixture of vapor water and hot water. The single – flash plant is an optimum way for geothermal energy turn into electricity. The vapor is a dominated fluid; this type can be used forthwith enter to the turbine. The schematic diagram of Figure (5) shows that the dry steam is promptly used to run the turbine blades [15].

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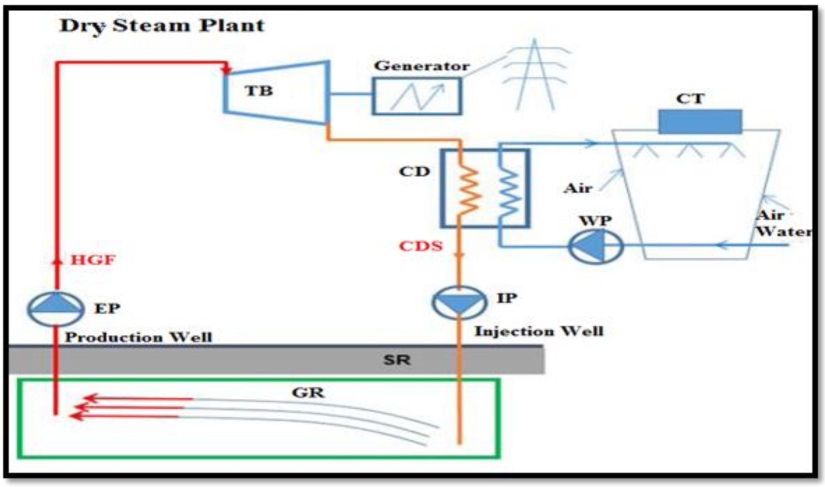

Fig. (5): Dry Steam Plant (TB: Turbine, CD: Condenser, WP: Cooling Water Pump, CT: Cooling Tower, CDS: Condenser, EP: Extraction Pump, IP: Injection Pump, GR: Geothermal Reservoir and HGF: Hot Geothermal Fluid.)

2.4. Binary Cycle for Geothermal Power Resources

A binary power plant cycle devolves the heat from well borehole by heating medium to the heat exchanger [14]. Binary geothermal power plants style build on a joint of Organic Rankine Cycle (ORC). It shows great promises in effectively utilizing these low-to moderate temperature resources [1]. Ordinary, there are two types of binary cycles; organic Rankine cycle and Kalina cycle. Therefore, if the hydrothermal fluid coming up from well is below (180°C), the ORC system will become more economical than flash cycle. Meanwhile, an admixture of water-ammonia is used as the heating medium in a Kalina cycle, when the hydrothermal fluid temperature in between (150-160)°C [11].

2.4.1. Organic Rankine Cycle

A binary system has three cycles: first is the brine heat exchange cycle of hydrothermal fluid where the heating medium absorbs heat from geothermal fluid via the heat exchanger. Second cycle is (ORC) working cycle process similar to conventional Carnot cycle converting the thermal energy to power energy in turbine and cooling system. These three cycles are separated, so that only the heat transfer takes place through the heat exchanger. The shell and tube heat exchanger are applied mostly. Figure (6) shows the schematic diagram of Rankine cycle [1].

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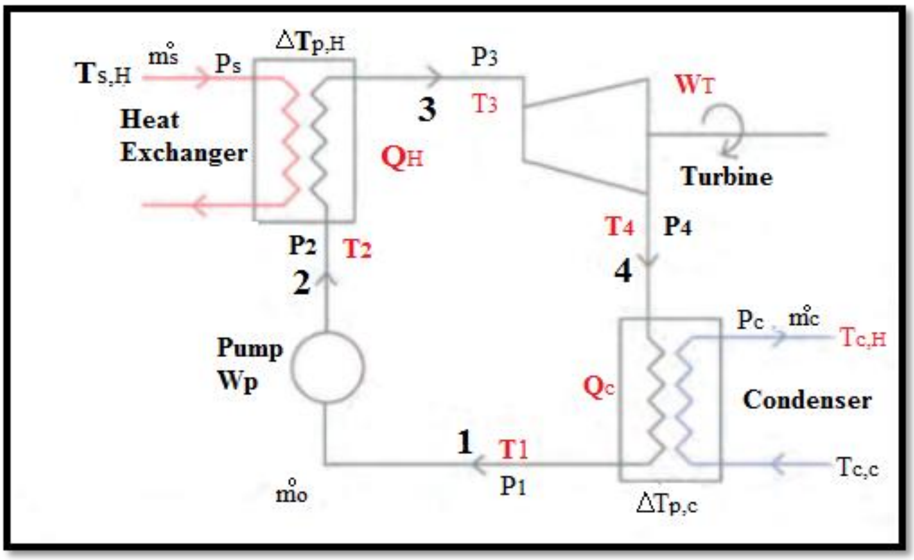

Fig. (6): Schematic diagram of a Rankine cycle.

2.4.2. Kalina Cycle for Geothermal Power Resources

The geothermal power researchers have a primary goal of the cost – effective production of electric sources from moderate temperature hydrothermal resources. Kalina cycle has a great deal of attention as possible enhancement to gas turbine power production [16]. Kalina cycle is modification of Rankine cycle that uses admixture heating mediums. Kalina cycle process proposed using the admixture of 70/30 ammonia water heating medium respectively. This cycle introduces two areas of improvement over conventional boiling Rankine cycle used with a variable temperature heat resource [17]. The benefits of this admixture at most for both vaporization and condensation happened at varying temperature. There is no simple boiling or condensation temperature sort of a boiling range, as well as condensation range. This according to the fact, that the phase change process is a combined process, both of phase change of the substance and absorption/separation of ammonia from water [14].

In the Figure (7) we can see the mass balance of a Kalina cycle. The cycle was satiated so the superheat vapor line out far of the cycle, the boiling fluid never happened in the evaporator and the vapor – liquid admixture was set apart yet. This is done in order to admixture the vapor temperature at vaporize outlet.

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The hydrothermal fluid enters from the well at the source inlet temperature of the system and normally uses the water as a heat source. The temperature of the water may not exceed than 150°C, and because the low heat source temperature superheat not adopted, the boiling temperature of ammonia and water is little so the Kalina cycle need a stripper to separate ammonia vapor from water vapor mixture to increase the ammonia concentration but in many cases the researches are not adopted the strippers, only separators were used instead [14].

The water in the mixture will not evaporate under the pressure more than 30 bar but only ammonia will evaporate so it only needs a gas liquid separator. The flow sheet of the process of the model in Figure (7) shows the basic model of Kalina cycle as below:

1) Ammonia water mixture is extended into vaporizer by S1 and evaporated from it to separator, line (4).
2) The ammonia rich vapor is separated in the separator and entered the turbine to generate power, line (5).
3) The ammonia-poor mixture concentration flows from separator to high temperature regenerator to be cooled in this state, line 7.
4) After a high temperature regenerate the liquid throttled down to the condenser pressure in line (8) and mixed with turbine outlet vapor at line (6).
5) The basic solution is cooled in the low temperature regenerator line 9 to line (10).
6) The heating medium enters the condenser to be cooled by cooling tower line (10) to line (11).
7) The low temperature and low pressure basic solution enter into the pump to increase the pressure of the heating medium up line (1).
8) The high pressure mixture enters the low temperature regenerator and high – temperature regenerator respectively in order to recover part of heat line (1) to line (2) to line (3), respectively.
9) Finally, the heating medium enters generator and complete the cycle, since the ammonia–water mixture could not be condensed in the usual ambient temperature [15],[16].

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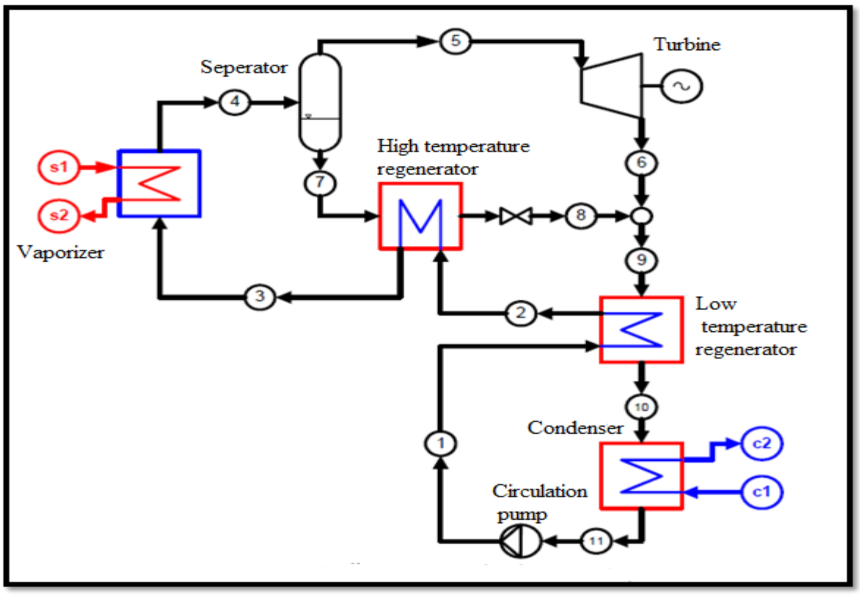

Fig. (7): Flow diagram of a saturated Kalina cycle.

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3. Geothermal Well Drilling Design

Despite the overall well drilling technology evolution and new feedbacks on exploration objects, the plan to autogenously heating sources for power grid is operated by comparable basic ways which have been drawn up for very early start of geothermal exploration well [18].

Drilling technologies are commonly in manufacture of oil then passed and adopted for the positive effects of geothermal power resources just as a result. Geothermal drilling technologies applied to flowing after oil industry development so far, during last decades, New Zealand and USA were started lead geothermal drilling technologies, and drilling technologies are still growing and improving especially on safety, knowledge, cost analysis and materials [18].

For holing estimation, the typical water wells vary considerably of hydrothermal and oil mineralogy. The difference is perfectly clear for well design perspective. Certainly, the water wells goals are usually shallower than the geothermal resources; water wells and geothermal wells at most differ for the temperature, pressure and hydrochemistry conditions [18].

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Geothermal drilling techniques are same to oil exploration concepts, however there are many certain specific differences to geothermal drilling and some modifications required to allow oil industries equipment to be used for drilling geothermal wells.

Drilling telescope activities downwards from larger to small diameters hole casings will be perfect way for drillings[4]. A design of long life wells for geothermal industry, civil expert engineers found a new criterion for this type of wells they apply 2 to 4 concrete envelope chains and the deepest well needs more chains. Certainly for deepest and hottest margins desire more than 5 layers of envelope chains for safety penetrate the high thermal reservoir [18]. The final concrete envelope is named the production envelope, and digging for expulsion spreads downwards from this layer, generally wells protected from crumbling by running cribriform high speed steel slotted liner to keep an open hole. The main aim for the enveloping the open hole is:

- To raise the open bore.
- For sealant out the aquifers and stopping water migration through different textures.
- Controlling blasts and anchoring the wellhead.
- Assorting a canal for well output.

Therefore, the essential strides of well design must be accomplished as bellow. The important purpose for the colossal number of envelope chains for high temperature wells is to upholding the hole and specially to provide safety in prevailing blasts. In general, geothermal wells are probably larger in the size than other industries wells. This enables production of more mass flow rate of the heating medium and hence more thermal power. Well locations are selected to let and obtain specific permeative geothermal goals in the reservoir. Conventional goals are permeative textures, nexus district between different textures, faults and slits. the researcher experience’s show that ordinary rock types usually make perfect storage targets in conventional geothermal resources [4].

Vertical wells drilling are easy ways when imaginable or when the targets are fairly bounded and are lower cost. Corrupt wells are drilled vertically at first and then after setting the anchor envelope the clay motor is used from the beginning step to build angle in the chosen direction until the end of reinforcement. Deviated wells are

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conventional as they admit the level crossing of many goals by an individual well and the boring of many wells from same drilling cleat. Thus will minimize the length of prostrate pipeline.

There were two type of swerved wells those are J and S shapes, J-shaped wells maintain this angle to total depth, while S-shaped wells can change their angle or direction when required, the change in well direction requires the use of clay motor, but changing the dangle angle can be done with modification in the bottom–hole assembly.

Horizontal drillings are a prevalent in sedimentary texture in petroleum and other industries but is not used in conventional two phase systems with fractured volcanic rock in order to the hole stability risks, however it could be an option for warm and hot water systems in sedimentary basins [4].

4. Geothermal Energy in Iraq

Iraq lies at the edge of the North-East of the Arabian Peninsula. The Iraq geography is described as a desert in the west and mountains of the Taurus and Zagros in the North-East, separated by the central fertile depression of Mesopotamia.

5. Thermal Gradient in Iraqi Tectonic Zone

The relation between heat flow and temperature gradient is represented by formula [8]:

$$Q = (dt/dz)\times A \qquad (1)$$

Where Q = Heat flow (kWm^{-2}), (dt/dz) = Temperature Gradient (°C/km), and A = Thermal Conductivity ($Wm^{-l}k^{-1}$). Temperature gradient derived from bottom-hole temperatures of numerous oil wells in Iraq and the surrounding countries is presented in Figure (8). The highest temperature gradient is recorded in W Iraq and NE Jordan reaches 40°C/km [8]. It is around 12 - l8°C/km along the Salman Zone and along the Tharthar and Tigris lines in N Iraq. The gradient increases to 20°C/km in the eastern side of the Mesopotamian Zone. The gradient along some of the structures of the Foothill is variable; some structures such as Kirkuk have a low thermal gradient, other

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like Hemrin have high thermal gradients exceeding 33°C/km. The thermal conductivity of the sedimentary cover was estimated from the average conductivity of 14 layers as a weighted average as shown in Figure (9). A uniform heat flow of 58 kWm^{-2} from the crust was used in conjunction with the averaged thermal conductivity to recalculate the temperature gradient. The calculated gradient differs little from the actual gradient in most of Iraq except in the W parts of the Rutba Subzone where the former is about 10°C less than the latter. This is attributed either to higher heat flow from the crust in that region or to the Neogenevolcanicity associated with the opening of the Red Sea which affected the W parts of the Arabian Plate with eruption of flood basalts in NE Jordan and SE Syria. Some buried volcanic bodies in W Iraq can also be determined from the aeromagnetic surveys of W Iraq.

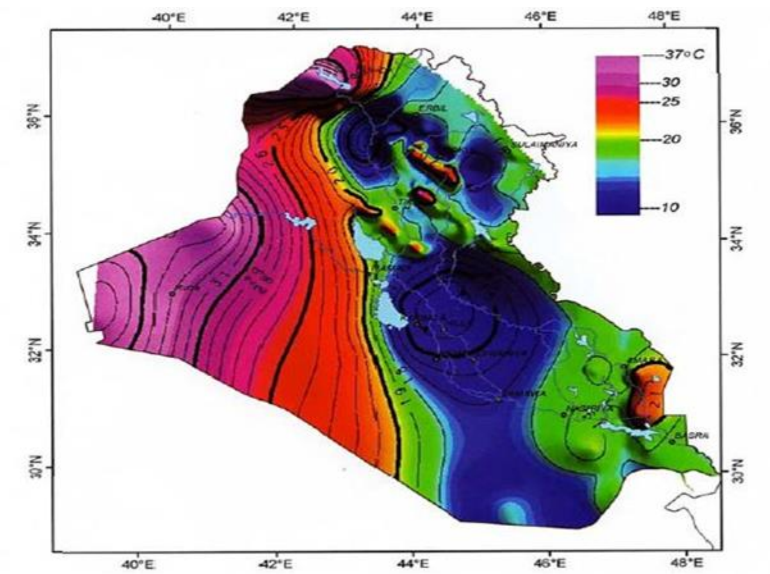

Fig. (8): Temperature gradient in °C/km derived from uncorrected bottom-hole temperatures [8].

Geothermal gradient of Kurdistan region was explored from 12 wells using the bottom-hole temperatures [8]. Horner plot was used to calibrate the non-equilibrium measured temperature because the mud circulation during drilling results in lower temperatures than the real temperature [8]. A cross section of temperature gradient in northern Iraq is shown in Figure (10). It is shown that the tectonic of northern Iraq is not suitable for geothermal energy for up to 4km depth.

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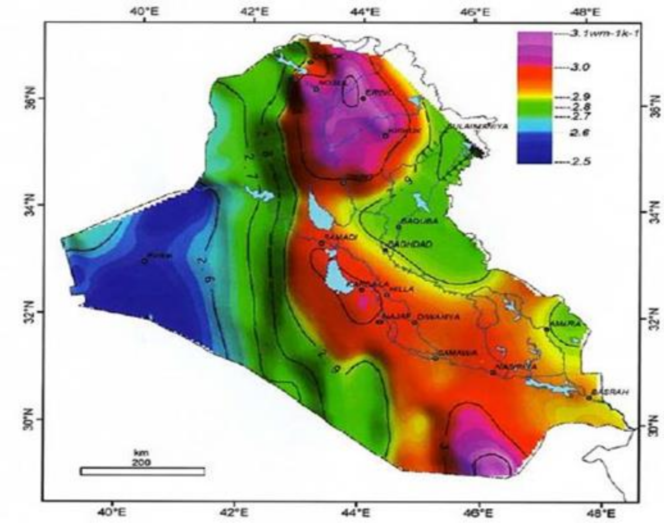

Fig. (9): Mean thermal conductivity of the sedimentary cover in ($Wm^{-1}k^{-1}$), calculated from the weighted average of thermal conductivity of 13 sedimentary layers [8].

- **Geothermal Gradient in Northern Iraq**

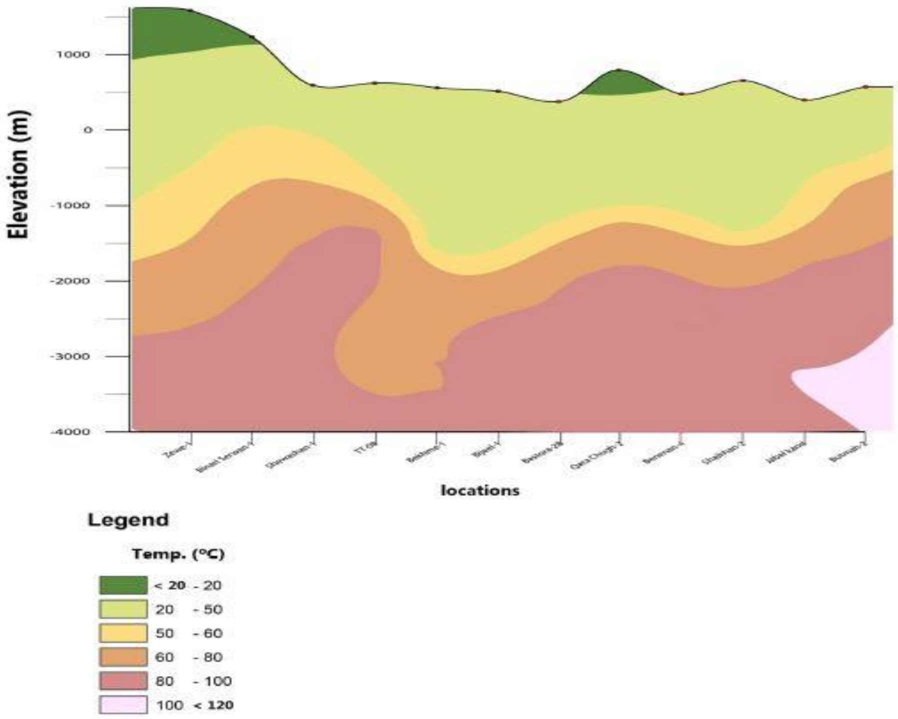

Fig. (10): A not-to-scale cross-section geothermal gradient in east to west Kurdistan region [8].

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6. Geothermal Gradient in Southern Iraq

The first published study on the geothermal gradient of southern Iraq was introduced in 1978 by Ibrahim [5]. The map was constructed by recording bottom-hole temperatures against drilling depth of eleven wells. However, the recorded temperature gradient was approximate because drilling mud gets into thermal equilibrium with surrounding rocks during drilling. In 1984, Ibrahim corrected his recorded temperatures using Kehle's empirical equation [19]. Figure (11) presents the geothermal gradient of southern Iraq after Kehle's correction.

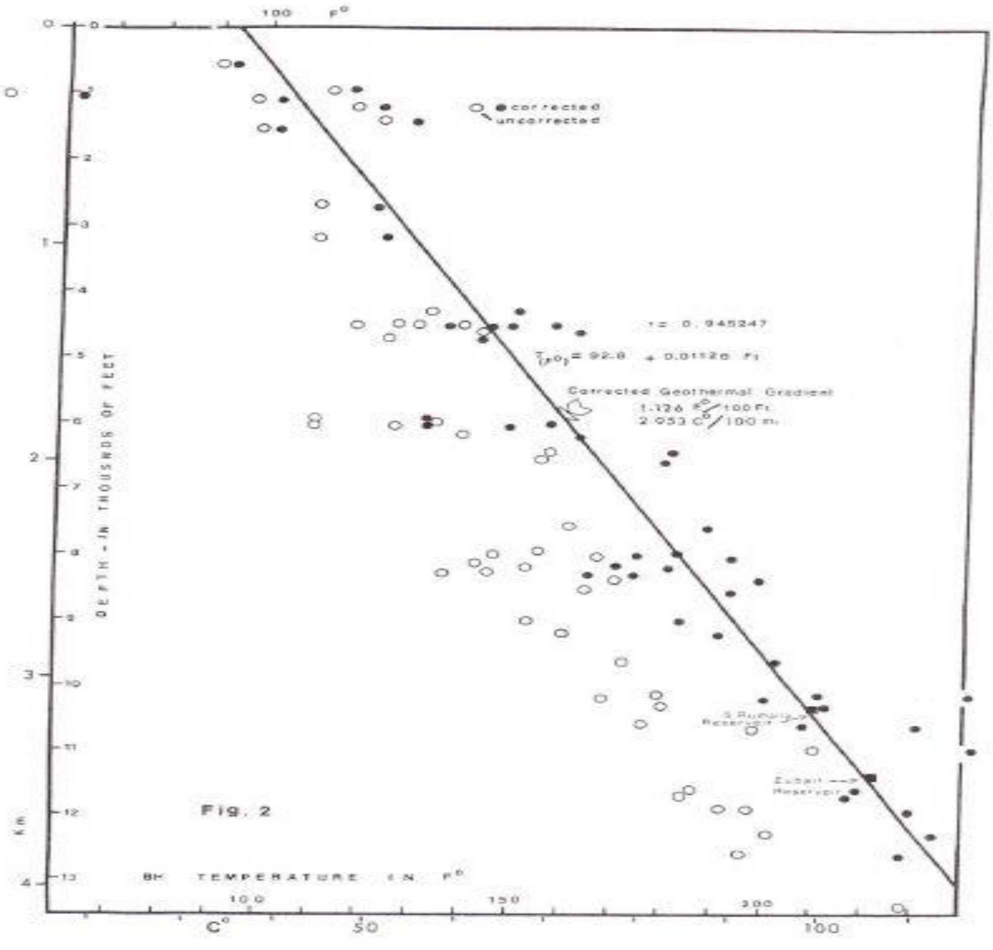

Fig. (11): Geothermal gradient of southern Iraq [19].

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7. Conclusions

According to previous studies and research regarding geothermal resources, the current study presents a review concerning temperature ingredient map to explore the maximum expected heat flow throw hot rock layers and to find the optimal exploration technologies.

From this review, it can be concluded that there is high potential of exploiting geothermal energy resource using Binary power cycles, especially in the W region parts of Rutba subzone. The expected temperatures may reach 280°C, and can be obtained in these disposals areas. To reach this temperature point, the drilling depth should be around 4000 m to 4500 m. These temperatures are high enough to run a binary power plant. However, the capital expenditure of the initial cost for the drilling of such deep wells and setting the power plant is very high. Moreover, the borehole drilling through that depth is encountered by very hard rocks layers that makes extremely hard to perform such drilling. However, since the operating expenditure is low because such plants require no fuel to run, the cost benefit can be realized over time, besides the environmental friendliness of this technology.

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