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Potential Geothermal Energy Utilization in Jordan: Possible Electrical Power Generation

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Abstract

Jordan, which is considered as part of the ring of fire, is tectonically active and could be considered as potential region for future generation of energy from the available geothermal energy resources. The current article discusses the possibility of utilizing geothermal energy in generating electrical power in Jordan. Jordan encounters geothermal energy resources in two main forms, medium and low energy with variation of temperature ranges from 110–114 ^{o}C and 30–65 ^{o}C, respectively. The various hot springs and wells have been subjected to a comparison in terms of temperature and flow rate in order to determine the most suitable method for electric power generation. This comparison concluded that electrical power could be generated using geothermal binary power plants and geothermal Stirling engines.

Keywords: *Geothermal Energy, Groundwater, Binary Power plant, Stirling Engine*

1. Introduction

With escalating awareness of the damaging effects of using fossil fuels on the environment, there has been a growing attention to provide the region with an abundant, clean renewable baseload energy sources. Renewable energy technologies are being developed to attain such clean sources of energy that have much lower negative impact on environment. In this regard, renewable energy resources appear to be a potential solution to energy and environmental problems and the key to the sustainable development.

According to [1], the geothermal energy is stored between the earth's surface and a specified depth in the crust. It is measured from local average annual temperature beneath a specified area. The most common criterion for classifying geothermal resources is based on the enthalpy of the geothermal fluids that act as the carrier transporting heat from the deep hot rocks to the surface. Enthalpy, which can be considered more or less proportional to the temperature, is used to express the heat content of the fluids, and gives a rough idea of their value. According to criteria that are generally based on the energy content of the fluids and their potential forms of utilization [2], the resources are divided into low, medium and high temperature resources.

Thousands megawatts of power are currently being produced could be developed from already-identified hydrothermal resources. With improvements in technology, much more power will be available. Usable geothermal resources will not be limited to the shallow hydrothermal reservoirs at the crustal plate boundaries. Much of the world is underlain by dry hot rock. Scientists worldwide have experimented piping water into this deep hot rock to create more hydrothermal resources that can be used in geothermal power plants [3]. As drilling technology being developed, allowing to drill much deeper, geothermal energy from hot dry rock could be available everywhere. At such time, we will be able to hit the true potential of the huge heat resources of the earth's crust and to create more efficient energy supply.

A complex plate boundary crosses Turkey and Greece where several high-temperature geothermal prospects have been found. Since 1984, the Kizildere field in western Turkey has produced 20.4 MWe. A dry ice plant was built in the late 80s. Lower temperature hot water (552 GWh/yr) is used for heating and in greenhouses in Turkey [4]-[7]. In Greece 37 GWh/yr is used directly, and in Milos a 2 MWe flash plant was operated for several years. Geothermal hot water is used in Algeria (460 GWh/yr) and Tunisia (400 GWh/yr) for bathing, greenhouses, drinking and irrigation purposes. In Israel and Jordan, the Red Sea-Jordan Valley Rift (JVR) hosts hot springs, with temperature up to 102 ^{o}C, and are used for bathing and heating (332 GWh/yr in Israel) [3].

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Several investigations on geothermal energy in the Hashemite Kingdom of Jordan have taken place over the last three decades [8]. These studies were conducted by the Natural Resources Authority in cooperation with several foreign institutions and companies. They found out rich geothermal potential in low temperature resources spread amongst several geothermal fields.

JVR is one of the most important areas supporting Jordan's economy. This populated area is located along the tectonic plate boundary that separates the Arabian and Sinai-African plates (Fig. 1). This plate boundary (Dead Sea Rift (DSR)) is one of the most seismically active regions in the Middle East, with over 4000 years of documented destructive earthquakes. The Ancient Lake of Lisan flooded over the rift valley during part of the last glacial period. Due to the tectonic activity along the major fault of the plate boundary, several sedimentary basin where formed. There are four basins of six in DSR are located within Jordan's territory. These are: Gulf of Aqaba, Wadi Araba, Dead Sea and Jordan Valley, whereas the Sea of Galilee and Hulla basins are located out side Jordan territory. The largest basin in Jordan is the Dead Sea basin. JVR extends to the north for more than 105 km, with several sub-basins formed along. The importance of studying of the JVR originates from its thick sediment filling the sub basins. This increases the potentiality of the geothermal energy.

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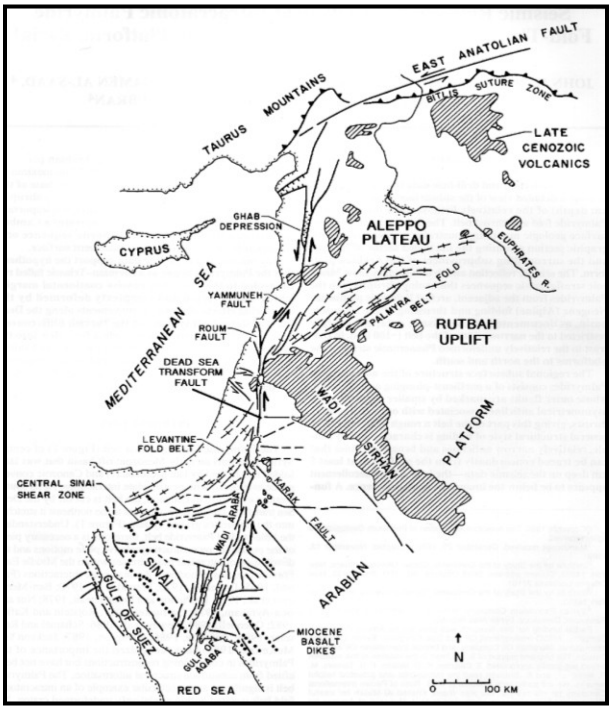

Figure 1. General tectonic map of the Middle East

2. Regional Geological Setting

JVR is a part of DSR, which is a site of a large scale tectonic movement. The motion along DSR initiated in the Middle Miocene (15.5 –11.5 m.y. ago). The movements along the Dead Sea fault are of strike-slip type. They were changed afterwards to sinistral strike-slip with a small component of oblique extension, resulting in the opening of basins along the rift [9]. Out of the 105-km total left lateral offset along the Dead Sea fault, only 30 km probably occurred in the last 5 m.y. [10]. Global plate tectonic models, on the other hand, indicate a faster differential motion between Africa and Arabia. Subsidence of the rift probably commenced in the Pliocene (5 m.y. ago) with the deposition of the evaporitic sediments in the Dead Sea basin. It was accelerated during the Pleistocene with the deposition of several km of lacustrine, fluvial and continental sediments [11].

Numerous destructive earthquakes occurred during historical times. Many of them have been documented in the Bible and in the later Roman and Arabic sources. The Dead Sea fault system north of Gulf of Aqaba can be subdivided into faults with segments that vary in length from 25 to 55 km [12] (Fig. 1). More fault segments are shown buried on seismic reflection profiles, which do not offset or perturb the upper sedimentary section, indicating that they are probably no longer active [13]-[15].

2.1. Groundwater and Tectonism

It is clear that DSR area is tectonically an active region (Fig. 2), and there are relationships between the groundwater, faults and fractures in the sedimentary basins. Such regional tectonic stresses could enhance and activate water conductive faults and fracture systems. Continental Rift systems, such as DSR, which extends from the Red Sea through the Dead Sea northward flanking and penetrating the coastal mountains of Lebanon and entering the Mediterranean Sea as well as splaying to the northwest into Syria, may be affected by such faults which may form water conduits.

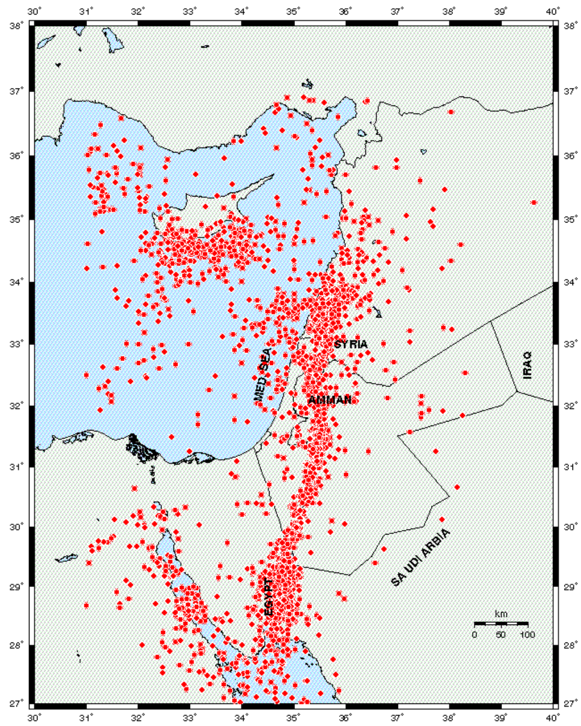

Figure 2. Tectonic activities along the Dead Sea Rift

The evidence of continuous seismic activity over several hundred m.y., combined with the chemical and physical characteristics of meteoric water on these fault, and behavior of brittle rocks, through which they percolate, could create very favorable environment for hydraulic continuum to be developed over geologic time.

Specifically, the geometry of a regional pervasive transform fault and associated fracture system will considerable broaden the flow path opportunities for high-pressure water. In the case of DSR groundwater system, the resulting fracture permeability presents a natural flow net within tectonic elements. The groundwater could be traveling in NNE, NNW, SSW and as well as E and W directions (Fig. 3).

There is currently no information concerning the order of magnitude of the mountain recharged groundwater flowing through the fractured rock to DSR. This shows how important it is to study the subsurface structural setting of JVR. Geothermal gradient, volcanoes, geysers, and hot springs are the visible expression of the heat in the interior of the Earth. This heat engenders by plate tectonics mechanism, thus Jordan has a promising source of geothermal energy being tectonically active region.

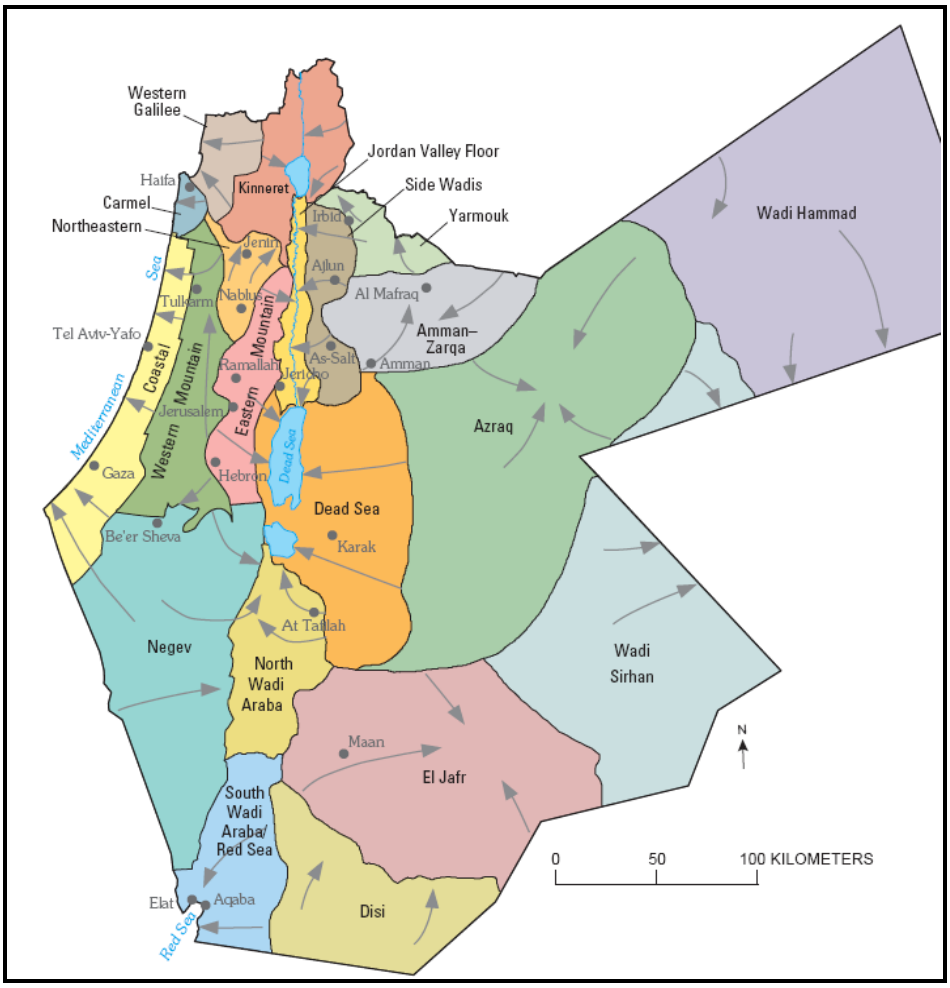

Figure 3. Groundwater resources in Jordan

2.2. Geothermal Resources in Jordan

The geothermal investigations found out a rich geothermal potential in low temperature resources spread amongst several geothermal fields. The geothermal gradient map (Fig. 4 a) of Jordan shows two distinct regions of high geothermal gradients up to 50 °C/km [8]. The first region is located in the immediate eastern vicinity of the Dead Sea escarpment. At this site many springs that discharge thermal water originate from the Lower Cretaceous Sandstone and form three main geothermal fields. These fields are: Mukhiebeh, Zara and Zarqa Ma'in, Afra and Burbeitta thermal springs (Fig. 4 b). The second region is located near the Jordanian border with Syria and Iraq. This area has several thermal wells discharge water from the Upper Cretaceous Limestone. In both regions, there are many shallow and deep wells discharging thermal water such as wells near Queen Alia airport, North Shuneh and Mukheibeh well. Table 1 shows the general characteristics of the main geothermal fields in Jordan [8].

Table 1. General characteristics of the major geothermal fields in Jordan [8]

Geothermal field	Temp. (°C)	Flow Rate (m^3/hr)
Himmeh springs	38-44	300-3000
Mukheibeh wells	30-41	200-6000
North Shuneh well	57	700
Queen Alia airport	30-45	30-100
Zara springs	34-55	1-255
Zarqa Ma'in springs	30-63	1-350
Wadi Ibn Hammad springs	35-41	1-25
TS-1D thermal well	50	400
Burbeitta spring	39	315
Afra springs	45-47	376
Smeika thermal well	57	50

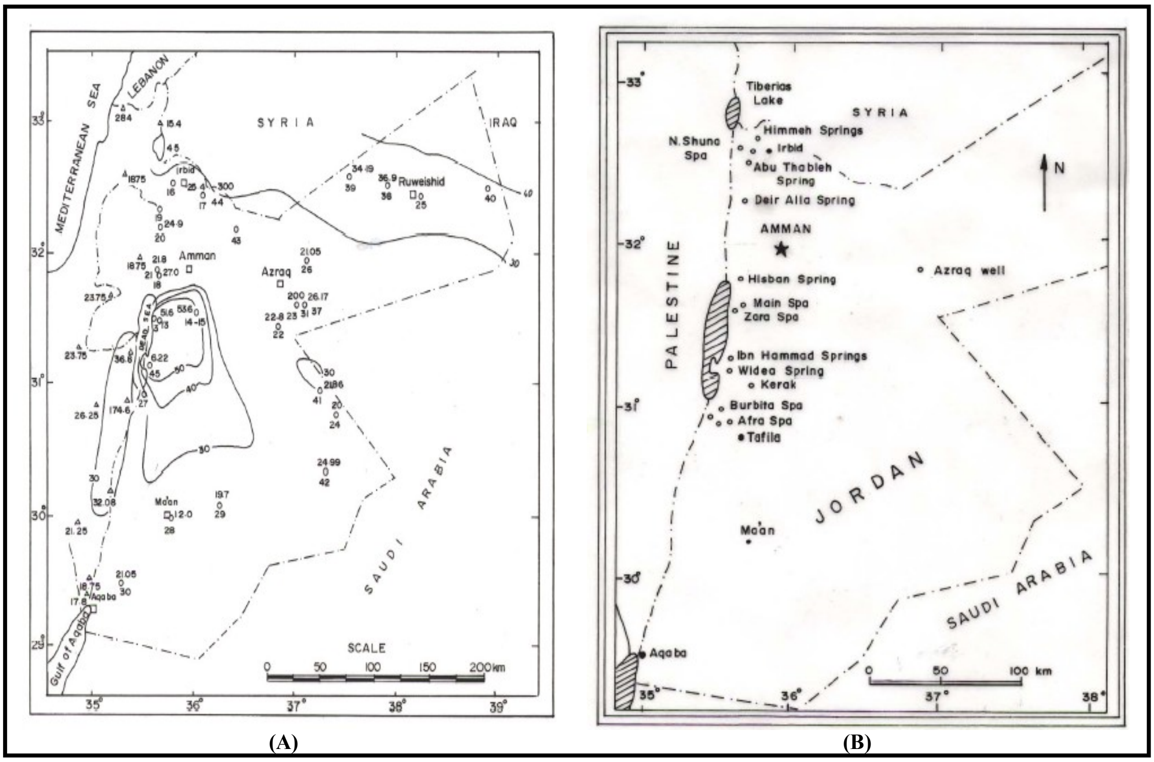

Figure 4. (A) Geothermal gradient map and (B) geothermal resources location map of Jordan [8]

3. Current State of electrical Power in Jordan

The Hashemite Kingdom of Jordan occupies a strategic location in the Middle East at an important crossroads for regional electrical energy integration. It is a developing non-oil producing country, where its energy requirements are obtained by importing oil from neighboring countries. The demand for primary energy in 2007 was about 7438 million tons of oil equivalent, with a growth rate of 3.5% against a growth rate of 2.3% in 2006 [16]. The cost of importing energy creates a heavy financial burden on the national economy. The levels of electricity consumption will double in the next 15 years.

Renewable energy applications in Jordan includes solar water heaters of more than 300,000 units, solar photovoltaic of more than 200 kW peak, wind farms of 1.5 MW, hydropower of about 5 MW and biogas of more than 3 MW. The total contribution of renewable energy in Jordan is about 3% of the total energy mix. In Jordan, there is a policy for the integration of renewable energy in the energy system by allocating 5% of the total energy from renewable energy sources within the next 10 years. This will be done by promoting renewable energy system in the electricity generation sector. Table 2 summarizes the current status of electrical power in Jordan [17].

Many Studies have been conducted by the National Energy Research Center with the British Geological Survey aimed at evaluating the potential of geothermal energy sources in Jordan.

It was found that there is a significant evidence of geothermal activity along DSR represented by: 1) Medium energy (110–114 °C) resulting from vertical tectonics and 2) Low energy (30–65 °C) resulting from aquifers heated by magmatic fluids. Therefore, the current investigation highlights the possibility of electrical power geothermal-based generation through geothermal binary electrical power plant and/or geothermal low temperature Stirling engine.

Table 2. The current status of electrical power in Jordan

Item	2006	2007	Growth (%)
Peak load of Jordan (MW)	1901	2160	13.6
Available capacity (MW)	2222	2322	4.5
Generated energy (GWh)	11120	13001	16.9
Steam units	6177	6904	11.2
Diesel units	32	14	-57.2
Gas turbines/diesel	67	32	-52.2
Gas turbines/natural gas	943	916	-2.9
Hydro units	51	61	19.6
Wind energy	3	3	-
Biogas	6	10	66.7
Consumed energy (GWh)	9593	10553	10.0
Energy exported (GWh)	12.7	176.1	-
Energy imported (GWh)	514	208	-59.6
Loss percentage (%)	17.43	18.89	-
Average (kWh) consumed per capita	2075	2277	9.7
Electricity fuel consumption (Thousand Ton of Oil Equivalent)	2725	3026	11.1
Heavy fuel	624	621	-0.5
Natural gas	1999	2396	19.9
Diesel	102	9	-91.1
Population under supply (1000)	5594	5717	2.2

3.1. Geothermal Binary Electrical Power Plant

The electrical power from the geothermal energy was originally being produced from the steam resources which are above 150 °C. But it is now being developed to produce from resources within the range of (80-150 °C) using the organic Rankine cycle process in binary power plants [18]-[20].

The binary cycle system incorporates two distinct fluid loops (Fig 5). The geothermal fluid in the first loop transfers its heat to the working fluid in the second loop. The geothermal fluid releases its heat to the secondary fluid through the heat exchangers, where the secondary fluid receives heat and vaporizes. The vaporized working fluid drives the steam turbine, and then it is cooled and condensed.

After condensing, the working fluid is returned to the heat exchanger, and the cycle begins again. By selecting suitable secondary fluids, binary systems can be designed to utilize geothermal fluids in the temperature range of 85–175 °C. The secondary fluid is operated through a conventional Rankine cycle. The used geothermal fluid is re-injected back into the reservoir to maintain reservoir pressure.

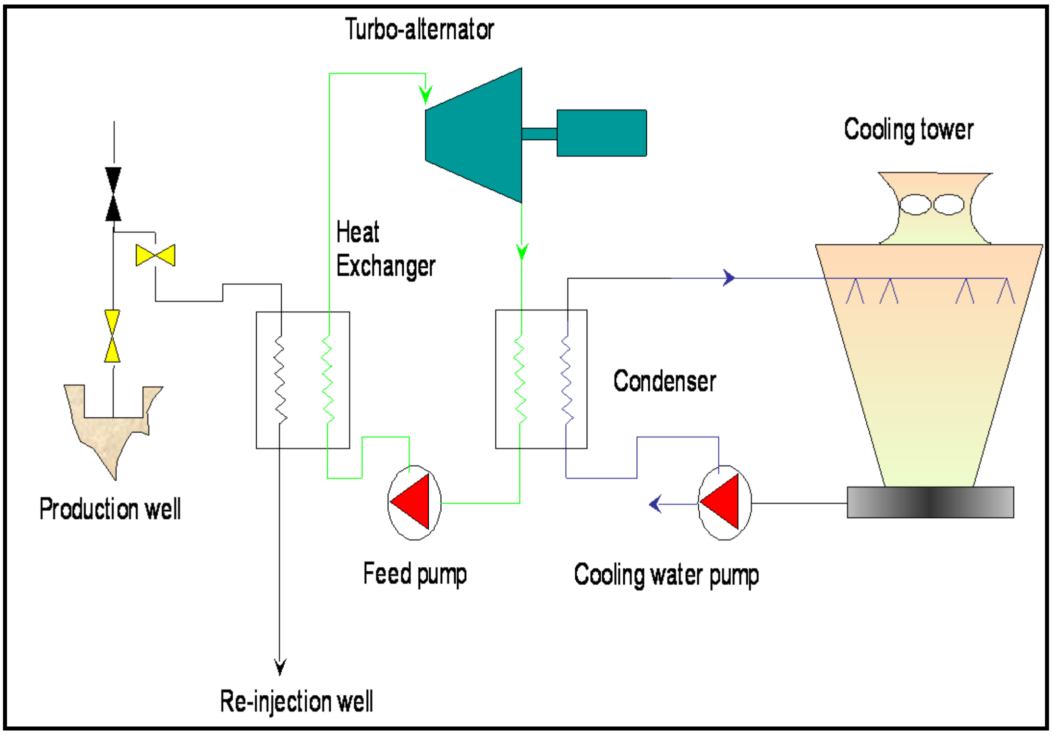

Figure 5. Scheme of the geothermal binary electrical power plant

3.2. Geothermal Low Temperature Stirling Engine

The low temperature potential of some geothermal reservoirs is a major disadvantage when it comes to power generation. Thus, Stirling cycle seems to be a better and more practical solution resulting in considerably higher efficiency. This is because it is thermodynamically equivalent to the optimum Carnot cycle [21].

The development of Stirling engine (Fig. 6) with the flat plate heat exchangers has shown that the low temperature geothermal reservoirs may also be successfully used for conversion of heat into mechanical work or electric energy. Hot water from the well circulates through a number of flat boxes connected with a crankshaft driven by a generator.

Additionally, the geothermal plant using the Stirling cycle has considerable technical and economic advantages when compared to the classic Clausius-Rankine process because there is no evaporator, condenser, feed water pump and numerous other associated elements. Low ΔT engines can reach 1 kW power according to the simplest equation called the square rule [21], the first approximation of power can be calculated knowing only the box length (l) in meters:

$$p = 0.253 \cdot l^2 \text{ (kW)} \quad (1)$$

Flat plate engine with box side length of 2 m could achieve approximately 1 kW power in an ideal case

If these huge plate areas are transformed into smaller ones making any modular variations, power is the same.

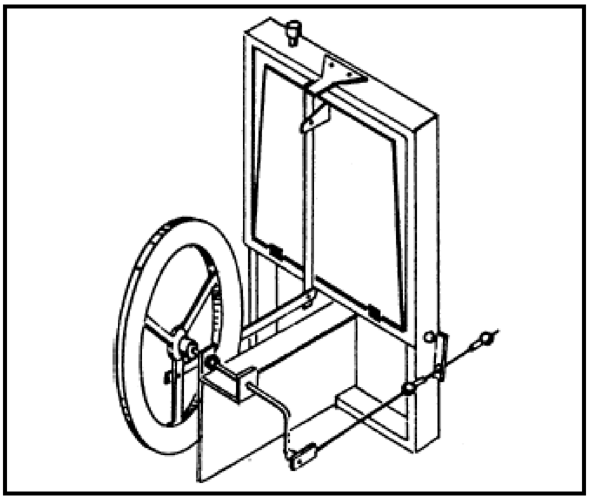

Figure 6. First flat plate low temperature Stirling engine

4. Conclusion

Geothermal energy is a potential alternative source of energy which could be used for different purposes such as; heating greenhouses, fish breeding, refrigeration and electric power generation. Jordan has a promising source of geothermal energy being tectonically active region. The collected data indicate that Jordan encounters geothermal energy resources in two main forms; medium and low energy with temperature variation ranges from 110–114 °C and 30–65 °C, respectively. Since the temperature of the geothermal resources in Jordan ranging between medium and low, the electric power generation could be achieved through the utilization of geothermal binary power plants at hot springs with temperature more that 80 °C and geothermal Stirling engine at hot springs with more than 20 °C difference in temperature. Thus it is recommended to further explore the feasibility of geothermal recourses in Jordan.

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