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# ANALYSIS OF THE POTENTIAL, MARKET AND TECHNOLOGIES OF GEOTHERMAL RESOURCES IN HONDURAS

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**ABSTRACT**

Honduras is a country with a significant geothermal potential that currently is not being exploited as a source of energy generation. Considering the above, this paper describes an analysis of the potential utilization of geothermal resources in the country. Various aspects are taken into account such as the existing legal framework regulating the energy sector, geothermal potential of Honduras and the identification of markets for geothermal resources. High, medium and low-temperature resources at different locations are considered. Different utilization technologies for power generation and direct uses are identified.

The main on-going activities related to geothermal development in Honduras are described. They will serve as lessons learned for potential public and private investors in this field.

## 1. INTRODUCTION

The world is moving toward an era of high costs of energy supply, which requires an adaptation of policies and country strategies. It has not only greatly increased the monetary costs but also environmental costs, social and political. This is the result of many factors: first, the enormous increase in global energy demand, driven by continued population growth and economic development, while the rate of discovery of new energy deposits has declined.

Environmental costs have also increased as the environment's capacity to absorb effluents and emissions has become saturated, largely from the processing and end use of energy. Environmental impacts include those caused by particulate matter, acid rain, and greenhouse effects resulting in climate change to which developing countries are most vulnerable because they lack the infrastructure and facilities to accommodate new circumstances; this results in costs in terms of public health, permanent damage to ecosystems, and risks to the safety of goods and people.

Honduras is also exposed to socio-political risks for its heavy reliance on imported energy, with obvious effects on the balance of payments and the risk of supply disruptions by geopolitical events. This situation will not change much, even when taking advantage of the full national energy potential.

Considering all the above, this paper presents the alternative of using geothermal natural resources for the generation of electricity and different direct heat uses. Highlighting these possibilities is important for promoting further development of geothermal resources in Honduras and, thus, taking advantage of the geothermal potential at different sites around the country. The legal aspects that provide an incentive for investment in such projects are also considered. New available technologies are discussed in relation with potential uses such as power generation using high and medium temperature geothermal resources, cooling, industrial processes, spas and other uses of low-temperature resources.

## 2. BACKGROUND

Geothermal research in Honduras began in 1976 when an expert sent by the United Nations, at the request of the National Electric Power Company (ENEE), conducted a preliminary survey of some thermal manifestations in the country. Such recognition indicated the areas of potential interest for the development of geothermal energy in Honduras. Those areas with potential were: Pavana (Choluteca Department) and San Ignacio (Francisco Morazán Department); as a result, it was recommended that a systematic exploration of the sites identified be conducted (Andara, 2009).

Based on these recommendations, ENEE hired in 1977 the USA firm Geonomics, Inc. to conduct a preliminary study of all the interest areas with geothermal potential (including the two areas mentioned above), and according to the results of this study, continue with further research in areas considered to be of preferential technical interest. "Geonomics, Inc.", however, could not complete the study and gave the ENEE in December 1977 progress reports indicating that the preferred areas remained Pavana and San Ignacio.

In 1978, the Government of Honduras again requested assistance from the United Nations to complete the investigations begun by Geonomics; ensuing investigations took place in 1979 as part of the second phase of the "Central American Energy Program" (Andara, 2009). A technical review of the work and results so far obtained concluded that it was advisable to concentrate efforts on a geochemical study of all thermal manifestations in the country, including those in the above mentioned areas.

This study was conducted by the USA firm Geothermex, Inc. in 1979 and 1980 and geothermal manifestations were classified into four groups (Andara, 2009):

1) *Areas with temperatures between 150 and 200°C:* (San Ignacio, Platanares, Azacualpa, Sambo Creek, and Agua Caliente).
2) *Areas with temperatures around 150°C:* (Pavana, Trinidad, El Olivar, San Rafael, Limones, and Los Almedros).
3) *Areas with temperatures between 100 and 150°C:* (Humuya, Aguacates, Quebrada Grande, and La Plazuela).
4) *Several areas with lower temperature than 100°C.*

The firm, Geothermex, recommended further research in the areas of groups 1 and 2, primarily through geochemical investigations. However, complementary geohydrological work carried out by geologists from ENEE in collaboration with United Nations experts recommended that the next phase include, in addition to geochemical studies of detail in these areas, geological mapping at 1:50,000 scale and 1:25,000 and geophysical surveys (geoelectrics and gravimetry).

From 1980 to 1984, geothermal investigations were halted for lack of financial resources. In 1985, as a result of requests made by ENEE to different international organizations, assistance was obtained for a total of 4.23 million USD of which 1.94 million were provided by USAID, through Los Alamos National Laboratory, and 2.29 million by the Government of Italy / UNDP. The general objectives proposed for this phase of research were:

1) Defining a master plan for national geothermal development;
2) Pose an alternative to geothermal power generation; and
3) Continuing investigations of the geothermal resource at a national level.

Geothermal research and wide recognition in Honduras were made at six sites:

| | | |
|---|---|---|
| Platanares | San Ignacio | Azacualpa |
| Pavana | Sambo Creek | El Olivar |

According to geological and geochemical results obtained, Platanares was selected by the temperature gradient and three wells were completed to depths ranging from 428 to 679 m. The geothermal team Los Alamos / USGS presented a report to ENEE, recommending geothermal assessment feasibility levels in this area.

## 3. LEGAL FRAMEWORK

Honduras currently has a legal framework that involves different aspects such as environmental, economic, social, technical and others, particularly in relation to the exploitation of natural resources for power generation. Following is a detailed explanation of the main laws and policies involved with the energy sector that are implemented jointly to generate a positive impact on the development of the country but, as in all cases, there are gaps to be filled. For example, in the case of the National Energy Policy, the responsible institution has worked on this issue since 2005, completing its preparations in 2010; this implementation is now expected to encourage public and private investment. The law is expected to promote electricity generation through renewable energy, but is basically oriented to electricity generation with water resources, leaving out the alternative to promote the use of other natural resources such as geothermal. That is why changes to this law are intended, as is the simultaneous elaboration of the regulations there under, which will contribute greatly to the use of other resources and technologies for energy generation in the country.

### 3.1 National energy policy

In view of having a still unexploited potential of natural resources available for clean energy and the possibility of using the regional electricity market in Central America, Honduras has several potential energy sources. In the face of growing dependence on oil and the imminent increase in international prices of fossil fuels, coupled with the necessity of changing the energy sector arrangement, the State of Honduras has taken the lead in the development of a long term sustainable energy policy. This energy policy must be able to develop various energy sources and guide both the government and the private sector to the planning and development of alternative energy sources and sustainable growth of the Honduran economy. In this paper, the various energy diagnoses and the potential for changing the Honduran energy mix are presented (Flores, 2011).

Considering the above, it has been the main goal to elaborate a single diagnosis about the use of geothermal resources as a source of energy and how to develop this type of alternative energy, taking advantage of the potential that has been studied.

Investment has been promoted with the goal of developing this clean energy potential, which could be used for direct uses or for electricity generation and, in this way, contribute to mitigating climate change by reducing greenhouse emissions. With this legal framework as support, Honduras is expecting to develop and promote its geothermal resources and thus increase electricity generation from renewables.

### 3.2 Law to promote electricity generation through renewable energy

The law to promote electricity generation through renewable energy was issued in October, 2007, considering such issues as: the economy, the need to design and implement a national energy policy, the use of national energy resources, and developing projects for power generation from natural and sustainable sources such as geothermal (Honduras National Congress, 2007). The promoting law of renewable energy aims to meet the following objectives:

1) Promote public and private investment in electricity generating projects using national renewable resources;
2) Promote investment in and development of energy projects using renewable resources, in order to diminish dependence on imported fuels;
3) Improve and simplify the permitting process to streamline the design and construction of new power generation plants using natural resources;
4) Create jobs in rural areas during construction and operation of projects;
5) Increase the efficiency of the national grid through a more distributed generation; and
6) Find new alternatives of energy generation through traditional sources.

Developers and operators of power generation projects using national renewable resources, whether a public or private company, are eligible for various incentives such as:

1) Exemption from taxes, tariffs etc. for all the equipment, materials, spare parts and parts directly related to the generation of renewable electricity;
2) Exemption of income tax and the like for a period of 10 years;
3) All benefits listed in the customs law regarding the importation of machinery and equipment necessary for the construction and operation of projects; and
4) Guarantee of the purchase and sale of energy according to various alternative trading in accordance with the laws.

### 3.3 Law of the electric subsector

The law of the electric subsector was issued in November, 1994, to consider the following obligations and needs (Honduras National Congress, 1994):

1) It is the duty of the state to regulate power generation in the country, establishing appropriate conditions to meet demand;
2) The supply of electricity in the country needs to be expanded and operational efficiency increased, with the participation of private enterprises; and
3) It is important to involve different regions of the country to improve the distributed generation of electricity.

The main objectives of this Act with regard to energy generation are to:

1) Establish conditions to meet the country's electricity demands at minimum economic cost;
2) Rationalize the use of the power resources of the country; and
3) Facilitate the participation of private companies in activities concerning generation and distribution of energy.

Public, private and mixed companies are included in this Act as regards the sale of energy generated; different alternatives will be established by agreement or contract.

## 4. GEOTHERMAL POTENTIAL

Geothermal energy stored in different regions could be used in Honduras for several purposes, for example cooling, bathing, industrial processes and electricity generation, using the heat from these sources in places where the topography of the ground permits; taking into consideration inherent requirements and the use of advanced technology, the country could take advantage of this resource.

### 4.1 Low-temperature resources

Approximately 204 hot springs have been identified in Honduras, where measured surface temperatures vary between 30 and 101°C (Table 1).

TABLE 1: Hot spring sites (low temperature) in Honduras, C.A.
(Source: Ministry of Natural Resources and Environment / General Direction of Energy data bank)

| No. | Location / Department | Number of sites | Temperature range (°C) |
|---|---|---|---|
| 1 | Atlántida | 11 | 45 – 101 |
| 2 | Choluteca | 20 | 32 – 98 |
| 3 | Colon | 13 | 36 – 96 |
| 4 | Comayagua | 15 | 32 – 90 |
| 5 | Copan | 13 | 36 – 101 |
| 6 | Cortes | 10 | 31 – 80 |
| 7 | Paraíso | 9 | 30 – 81 |
| 8 | Francisco Morazán | 15 | 36 – 70 |
| 9 | Gracias a Dios | - | - |
| 10 | Intibucá | 10 | 33 – 55 |
| 11 | Islas de la Bahía | - | - |
| 12 | La Paz | 14 | 34 – 85 |
| 13 | Lempira | 20 | 40 – 98 |
| 14 | Ocotepeque | 7 | 36 – 52 |
| 15 | Olancho | 16 | 52 – 74 |
| 16 | Santa Bárbara | 13 | 30 – 100 |
| 17 | Valle | 10 | 30 – 56 |
| 18 | Yoro | 7 | 40 – 67 |

A map was created of hot springs with temperatures between 30–105°C, with the purpose of showing the different sites with low-temperature geothermal potential in Honduras. The distribution of these hot springs around the country is shown in Figure 1, as well as the geological formations.

### 4.2 High-temperature resources

As indicated earlier, studies concluded that there is potential in six sites (Platanares, San Ignacio, Azacualpa, Sambo Creek, Puerto Cortes and Pavana) around the country for electricity generation (Table 2; Figure 2).

A map was created of hot springs with temperatures between 120-230°C to show the different sites with high-temperature geothermal potential in Honduras. The distribution of these hot springs around the country is shown in Figure 1, as well as the different projects for electricity generation.


FIGURE 1: Hot spring sites (low temperature) in Honduras, C.A.
(Source: Ministry of Natural Resources and Environment / General Direction of Energy data bank)

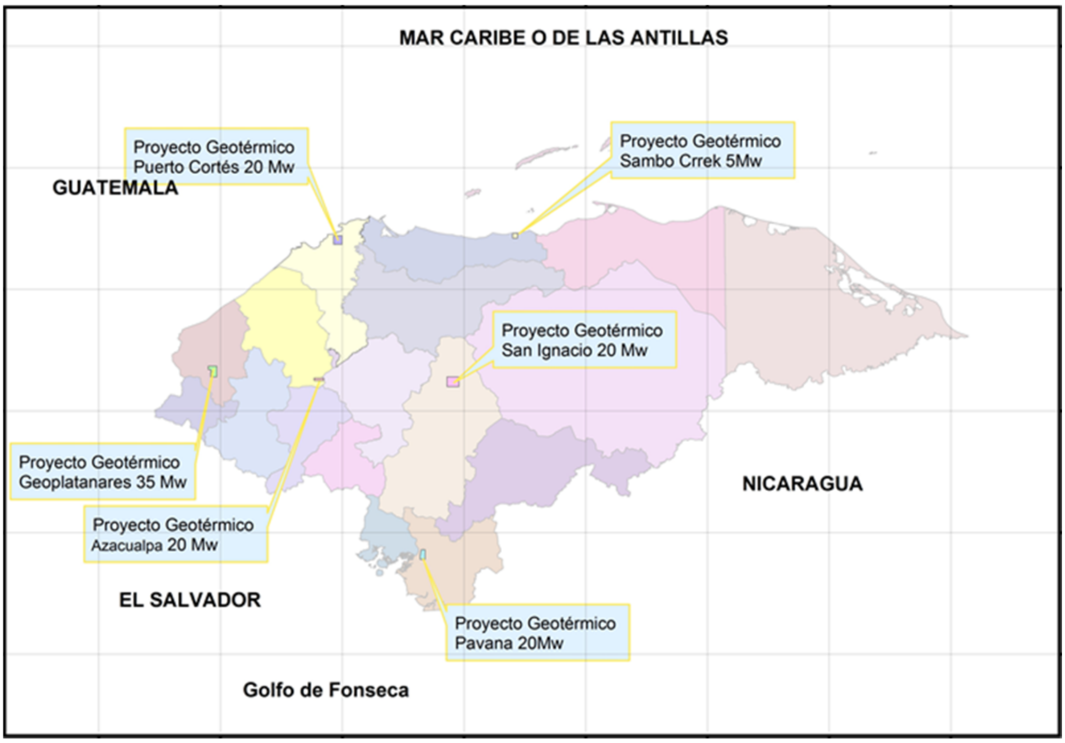


FIGURE 2: Hot spring sites (high temperature) and potential for
electricity generation in Honduras, C.A.
(Source: Ministry of Natural Resources and Environment / General Direction of Energy data bank)

TABLE 2: Hot spring sites (high temperature) in Honduras, C.A.
(Source: Ministry of Natural Resources and Environment / General Direction of Energy data bank)

| No. | Project name (geothermal) | Location | Potential for elect-ricity generation (MW) |
|---|---|---|---|
| 1 | Platanares | La Union, Santa Rosa de Copan | 35 |
| 2 | Azacualpa | San Pedro de Zacapa, Santa Barbara | 20 |
| 3 | Pavana | Choluteca, Choluteca | 20 |
| 4 | Puerto Cortes | Choloma, Puerto Cortes y Omoa, Puerto Cortes | 20 |
| 5 | San Ignacio | El porvenir, Cedros y San Ignacio, Fco.Morazán | 20 |
| 6 | Sambo Creek | La Ceiba | 5 |

## 5. TECHNOLOGIES AND MARKETS FOR GEOTHERMAL ENERGY IN HONDURAS

There are no geothermal projects developed in Honduras so far, but there is a potential market in different kinds of uses such as electricity production and some direct uses such as cooling, industrial processes and bathing, especially considering that Honduras has a lot of activity in manufacturing and tourism companies. Also, due to the weather and the high temperature, cooling is needed in various settings, such as supermarkets and other industries.

Considering the various aspects for improving geothermal development, with due regard to the energy market in Honduras, has resulted in the identification of different uses and technologies with economic potential (Table 3).

TABLE 3: Resources, uses and technologies relevant to geothermal energy development in Honduras

| Resources | Use | Technology |
|---|---|---|
| High- and medium-temperature resources (100-200°C) | Electricity generation | Organic Rankine Cycle |
| Low-temperature resources (30-100°C) | Cooling systems<br>Industrial processes<br>Bathing pools or spas | Absorption systems<br>Simple direct use with heat exchangers<br>Simple direct use with heat exchangers |

### 5.1 Electricity generation

Most geothermal electric power generation systems utilize high-temperature geothermal resources (>200°C) where the extracted steam drives turbines to create mechanical work. There are different phases or processes during electric power generation such as the separation process of geothermal fluid, creating mechanical energy, generating electricity from mechanical energy and disposing of the geothermal fluid after the power generation process (Tesha, 2009).

A geothermal electric power generation process is basically similar to a steam power generation process based on fossil fuel, with a steam creation process distinct for both power generation systems. Steam, in geothermal power generation systems produced from geothermal wells, can be either in the form of dry steam or liquid-steam mixtures. Dry steam from a geothermal well can be used directly to generate power, while flashing and a separation process are needed for liquid-steam mixtures of geothermal fluid. Multi-stage flashing power generation cycles are mostly used for liquid dominated geothermal resources.

However, by using the appropriate power generation technologies, it is now possible to generate electric power from a lower temperature geothermal resource (~100°C) using a binary-cycle method. Performance and capital cost of a flashing cycle depend on a large and expensive low pressure steam turbine; in a binary cycle, they are based on the primary heat exchanger and condenser.

As already noted, there are currently six projects under exploration in Honduras. Some of them are more advanced in the financing phase than others. The average temperature for most of the surveyed projects is between 120 and 200°C; the available technology for power generation using geothermal resources with this range of temperature builds on the Organic Rankine Cycle.

*Organic Rankine Cycle, ORC*

An Organic Rankine Cycle uses a secondary liquid for delivering energy from geothermal fluid to the application. The working fluid receives heat from the geothermal fluid through a heat exchanging process. As the working fluid extracts heat from the geothermal fluid, it starts to vaporize and is then used to drive a turbine. The low pressure fluid exhausted from the turbine undergoes a condensation process where it is prepared for the next evaporation cycle. Thus, the working fluid circulates in a closed loop system (Tesha, 2009).

The Organic Rankine Cycle is an important conversion process when a low-temperature geothermal resource cannot drive a steam turbine directly or when a geothermal fluid is too contaminated with dissolved gasses or corrosive minerals which can either jeopardize the turbine or become a problem in the flash cycle. Nowadays, the addition of a bottoming unit based on the Organic Rankine Cycle in a flash steam plant is looked upon favourably, as it enables the utilization of low grade thermal energy from waste brine water.

Since the Organic Rankine Cycle is employed in the utilization of low and medium temperature geothermal fluids, it is important to ensure that the fluid temperature at the outlet of the evaporator and reinjection well is kept above the point where silica scaling and other chemical problems begin. Keeping the geothermal fluid under pressure is one alternative that could overcome this problem.

A simplified layout of an Organic Rankine Cycle is illustrated in Figure 3, although it could be simplified more by removing the recuperation unit from the system. The recuperator is an additional unit that can increase the efficiency of the cycle by accommodating an appropriate heat exchange internally.

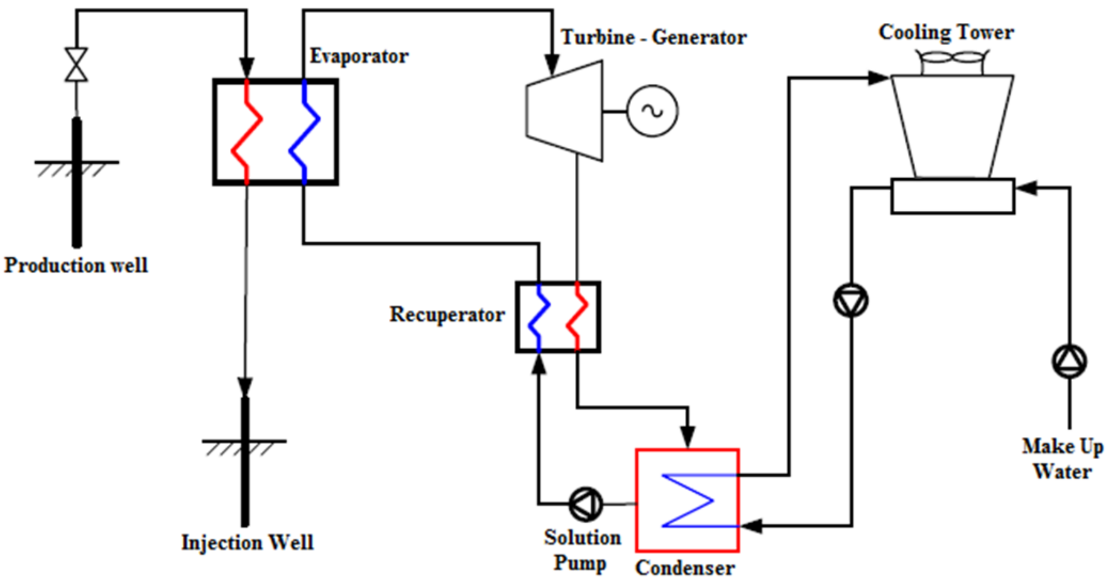


FIGURE 3: Simplified layout of an Organic Rankine Cycle with recuperation unit (Tesha, 2009)

TABLE 4: Thermodynamic properties of some candidate working fluids for binary plants (Tesha, 2009)

| Working fluid | Formula | Critical temperature (°C) | Critical pressure (kPa) |
|---|---|---|---|
| Ammonia | $NH_3$ | 133.65 | 11,627 |
| Isobutane | $i\text{-}C_4H_{10}$ | 135.92 | 3,685 |
| Isopentane | $i\text{-}C_5H_{12}$ | 187.80 | 3,409 |
| n-Butane | $C_4H_{10}$ | 150.80 | 3,718 |
| n-Pentane | $C_5H_{12}$ | 193.90 | 3,240 |
| Propane | $C_3H_8$ | 96.95 | 4,236 |
| Water | $H_2O$ | 374.14 | 22,089 |

There are many choices for the working fluid of an Organic Rankine Cycle. The selection of the fluid is based on the characteristics of the geothermal fluid, especially the temperature (Table 4). The most common and widely used working fluids are hydrocarbon based fluids such as isobutane, isopentane, and propane. A good design and selection of a working fluid delivers optimum efficiency, both technically and economically for a given geothermal fluid condition.

## 5.2 Direct uses

Direct use of geothermal energy refers to the use of the heat energy of low, medium and high-temperature geothermal water without conversion to some other form of energy such as electrical energy. The hot water can come from geothermal wells, springs or a separation process of geothermal fluid mixtures.

Conventional direct uses of geothermal fluids have been applied for long periods of time where communities utilize hot springs for bathing and balneology. Nowadays, in modern direct use systems, the hot water is produced from a drilled geothermal well involving preliminary and conceptual design of a direct use project together with reservoir testing and evaluation. Most geothermal direct use systems use heat exchangers to keep the geothermal fluid separate from the working fluid that conveys the heat from geothermal fluids to the application. Development of direct use systems, especially when heat exchangers are not used, requires careful corrosion engineering if the most cost effective material selections and design choices are to be made.

The use of high-enthalpy geothermal resources for the generation of electric power continues to be more popular than the use of lower enthalpy resources, even though the economic as well as environmental benefits of using moderate- to low-enthalpy fluids for direct use are still promising. Indeed, moderate- to low-enthalpy is widely applied in non-tropical regions where space heating demand is very high, not to mention the use of geothermal fluid for industrial purposes such as agricultural and drying processes. However, one problem in the developmental process of direct use is the fact that geothermal waters can only be transported over a limited distance due to the high cost and the heat loss along the transmission line.

As is known in many countries around the world, mainly in Europe, direct use of geothermal resources provides many benefits; that is why in those countries the level of utilization is high, due to the varied application of geothermal heat, such as for snow melting, greenhouses, fish farming, district heating, swimming pools, industrial processes and others, but in warm countries like Honduras the applications are more limited.

Considering the climate of Honduras, the different direct applications that can be taken advantage of in the country are addressed in the following sections.

### 5.2.1 Cooling systems

Cooling or a refrigeration system is a process used to remove heat from an object, especially in a confined space, rejecting the unwanted heat into a specific preferable environment; we also can say that the cooling process is a method to lower the temperature of an object. There are two common cooling systems which are commonly used: compression cooling system and asbsorption cooling system (Tesha, 2009).

A compression cooling system utilizes a mechanical compressor, electric motor, to mechanically drive the heat transfer from a low temperature to a high temperature. In an absorption cooling system, two heat exchange units replace this mechanical compressor: these are a generator (desorber) and an absorber, which create heat transfer from a low temperature to a high temperature. Even though these two units replace the function of a mechanical compressor, an electric pump is used in an absorption cooling system as a simple way to circulate the working fluid from the low pressure level to the high pressure level. This electric pump will consume energy, but it is a small amount compared to the overall system (Tesha, 2009).

Generally, a single substance working fluid is used for the entire heat transfer process within a compression system; however, this cannot be realized in an absorption system. In an absorption system the working fluid consists of two or more substances which act as absorbent and refrigerant. The refrigerant is the real working fluid for the refrigeration process and the absorbent will treat the refrigerant to a specific condition for complete cycle continuation.

There are two important advantages of the absorption cycles compared to other cycles with similar production:

- No large, rotating mechanical equipment is required;
- Any source of heat can be used, including low-temperature sources.

*Absorption cooling system*

An absorption cooling system is a process activated by a thermal cycle; this type of system exchanges the thermal energy with its surrounding environment. Often this system operates at lower pressure than the atmospheric pressure, as the pressure is regulated by the vapour pressure of the working fluid. The vapour pressure of the working fluid is strongly related to its temperature. An absorption system could be a single effect or more advanced multiple effect absorption cycle (Tesha, 2009).

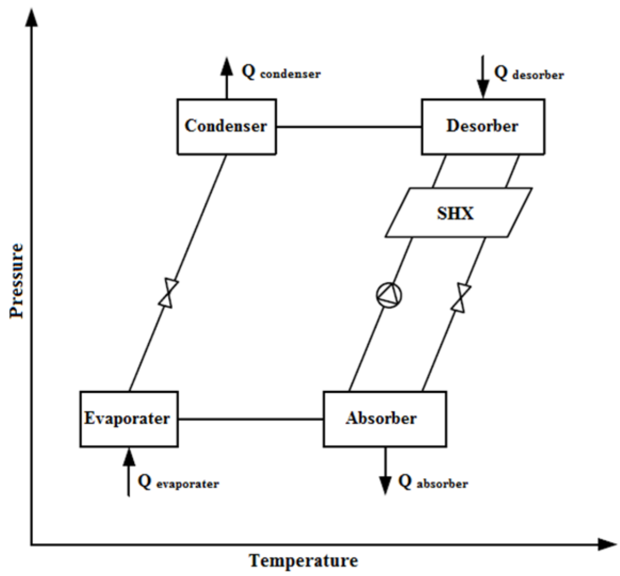


FIGURE 4: Single effect cooling system diagram (Tesha, 2009)

A single effect cooling system consists of two flow restrictors, one solution pump, and five heat exchangers; four of these transfer the heat from the external source and the rest work internally within the system as a solution heat exchanger. It is common to install a solution heat exchanger in a basic single effect absorption refrigeration system to increase refrigeration performance.

Figure 4 shows a specific diagram of the components of an absorption cooling or refrigeration system; it describes the cycle based on the temperature and pressure level of each component and their position in the system, as well as their energy transfer between the system and the environment. As a basic representation of a specific heat transfer process, the diagram can only show in a schematic way the saturated states while the superheated and sub-cooled states cannot be accurately presented. The arrows indicate the flow of the energy from the system out to the external environment and the energy flow that is supplied to the system. Heat is injected into the system through the desorber and the evaporator and heat rejection is achieved through the absorber and condenser.

Two or more substances working together as a single solution of working fluid are always required; this produces several variants of refrigerant – absorbent pairs in the absorption cooling systems industry. The refrigerant should be more volatile than the absorbent so that the two can be separated easily. Water is usually used as the refrigerant for solid absorbents.

Water-ammonia and lithium bromide-water are the most common fluids and still have desirable properties compared to other working fluids, mainly for the high amount of latent heat which can minimize the need of refrigerant flow rate. The combination of water-ammonia is favourable for sub-zero refrigerant temperatures while the lithium bromide-water combination is limited to temperatures above the freezing point of water.

*Absorber*
The absorber is a component where the absorbent and the refrigerant vapour are mixed together. It is equipped with bundles of tubes, a heat rejection system, and operates under a low pressure level corresponding to the evaporator temperature.

The absorption process can only operate if the absorber is at a low-temperature level, hence the heat rejection system needs to be attached. The mixing process of the absorbent and the refrigerant vapour generates the heat of condensation and raises the solution temperature. Simultaneous with the developmental processing of latent heat, heat transfer with cooling water will then lower the absorber‘s temperature and, together with the solution temperature, create a well mixed solution that will be ready for the next cycle. A lower absorber temperature means more refrigerating capacity due to a higher refrigerant's flow rate from the evaporator.

*Generator/desorber*
The desorber works with a high pressure which is controlled by the temperature of the incoming heat to the desorber or the condensation temperature required by the cooling water entering the condenser. The desorption process produces vapour and extracts the refrigerant from the working fluid by the addition of external heat from the heat source; it could be desorption of water out of a lithium bromide-water solution or ammonia out of a water-ammonia solution. The refrigerant vapour goes through the condenser while the liquid absorbent is gravitationally settled at the bottom of the desorber; there is a pressure difference between the desorber and the absorber which causes it to flow out to the absorber through the expansion valve.

*Condenser*
The liquid state of a refrigerant is needed to run the refrigeration process. Hence, the vapour phase of a refrigerant from the desorber is altered to a liquid by the condenser. The condensing process of a high pressure refrigerant vapour is done by rejecting the heat of the vapour to the sink. The sub-cooled liquid from the condenser goes through the expansion valve which lowers the pressure level; a consequence of this process is that some low quantity may flash into vapour, but the refrigerant will still be able to take latent heat from the environment.

*Evaporator*
The evaporation temperature regulates the lower pressure level of the absorption system. The low pressure of two phase refrigerant from the flow restrictor continues to evaporate because of the addition of latent heat from the refrigeration surroundings. A complete evaporation process will convert the two phase refrigerant completely into the gaseous phase.

*Expansion valve*

The goal of the expansion valve is to reduce the pressure and split the two different pressure levels. In a single effect absorption refrigeration system, the pressure change is assumed only to occur at the expansion valve and the solution pump and there is no heat added or removed from the working fluid at the expansion valve. The working fluid enthalpy remains the same on both sides. There is no mass flow change between the two end points of the expansion valve and the process is assumed to be an adiabatic process. However, the pressure change through the expansion valve can generate a small amount of vapour via flashing and thus increase the volume of the fluid.

The existence of the Solution and Refrigerant Heat Exchangers (SHX, RHX) will drive the expansion valve's input fluid close to a sub-cooled state, and at the end it will influence the amount of refrigerant flashed out of the expansion valve.

Another thermodynamic changing process across the expansion valve is the possibility of a lower temperature at the end of the flashing process as some amount of energy must be taken from the liquid phase in order to drive the phase change. In this way, the amount of refrigerant flash will affect the level of the temperature drop across the expansion valve.

*LiBr-$H_2O$ absorption system*

The aqueous solution of lithium bromide is one of several solutions that are used in absorption systems that are used for heating and cooling purposes. Many years ago when the technology was not so developed, it was used by several manufacturers in the U.S., where water acted as the refrigerant which absorbed and removed heat from the specific environment while lithium bromide became the absorbent that absorbed the water vapour into a solution and made it possible to be circulated by a solution pump (Tesha, 2009).

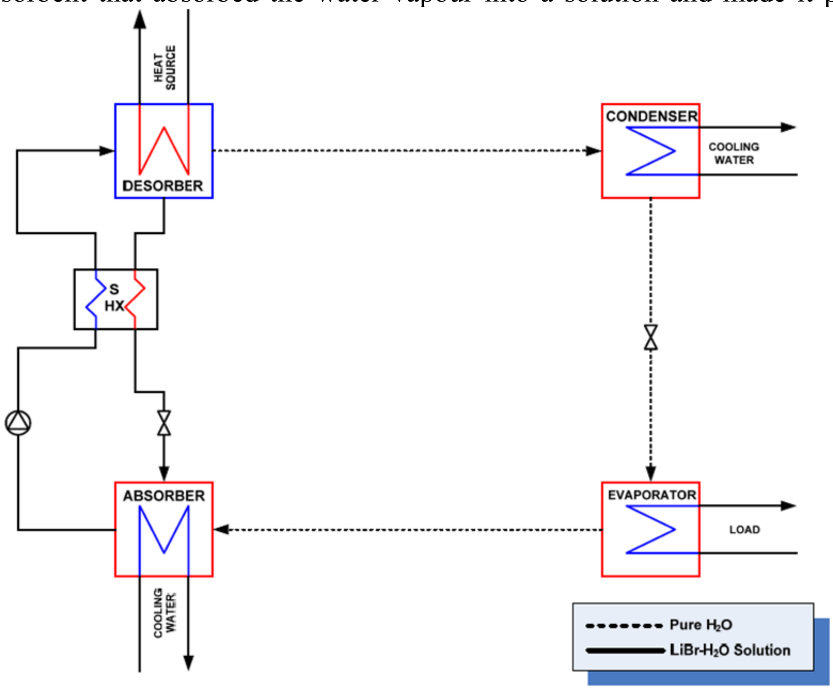


FIGURE 5: Single effect LiBr-$H_2O$ absorption refrigeration system (Tesha, 2009)

Using lithium bromide as an absorbent is most important because it is essentially non-volatile, resulting in cycle designs that avoid the need of rectifiers. Water is useful as the refrigerant because it does not crystallize; its limitation is that it will make the system work only for refrigeration temperatures above 0°C or even 5°C, because of the freezing point of water. Figure 5 shows the diagram of a single effect LiBr-$H_2O$ absorption refrigeration system.

*$H_2O$-$NH_3$ absorption system*

Water-Ammonia is an absorption fluid that was used for many years in ice production prior to the introduction of vapour compression technology. Ammonia is highly soluble in water and the solubility increases as the water temperature decreases at a constant pressure. In this type of system, ammonia is the refrigerant fluid which removes heat from the specific environment while water becomes the absorbent that absorbs ammonia vapour into a solution and makes it possible to be circulated by a pump. The vapour pressure of a water-ammonia solution is less than that of pure ammonia at the same temperature. Compared to the lithium bromide system, the low volatility ratio between ammonia and water requires a high operating pressure (Tesha, 2009).

Using ammonia as a refrigerant gives the advantage of working at a much lower refrigeration temperature because it has a lower freezing temperature (around -77.7°C) than water, even though due to its toxicity level limits, the use of ammonia requires good ventilation or an outdoor location. Steel or stainless steel is the most common material for the construction of a water-ammonia system. Figure 6 shows the diagram of a single effect $H_2O$-$NH_3$ absorption refrigeration system.

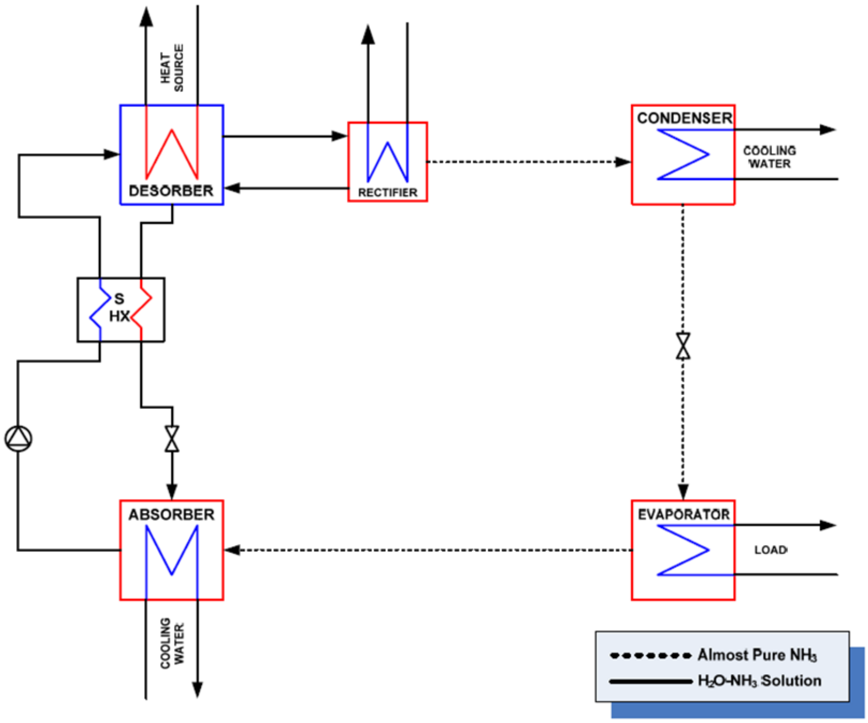


FIGURE 6: Single effect $H_2O$-$NH_3$ absorption refrigeration system (Tesha, 2009)

The water-ammonia absorption cycle is similar to the lithium bromide-water cycle except for some important differences in working fluid properties such as: ammonia has a lower latent heat than water; the different pressure and range of solubility; and the volatility of the absorbent. The latent heat of ammonia is only about half that of water; thus, the refrigerant and absorbent mass circulation rates have to be double that of water-lithium bromide in order to reach the same cooling capacity.

*Rectification*
Rectification acts as the condenser with the same water cooled effect, but with a relatively small capacity of condensation. The goal is to condense the available water fraction that is carried away together with the strong ammonia solution and send it back to the desorber as reflux. Ammonia-water vapour mixture is cooled a bit and a small portion of the vapour condenses and returns to the desorber. This process of water removal increases the purity of ammonia in the strong refrigerant solution.

### 5.2.2 Industrial processes

Geothermal energy may be used in a number of ways in the industrial field. Potential applications include drying, process heating, evaporation, distillation, washing, desalination, chemical extraction and others.

The most important energy considerations for an industrial complex are cost, quality, and reliability. Geothermal energy may be attractive to an industry provided: (a) the cost of energy / kg of the product is lower than that presently used, (b) the quality of the geothermal energy is as good or better than the present supply, and (c) the geothermal energy will be available for the life of the plant. Reliability and availability can only be proven by long-term use or testing (Lienau, 2003).

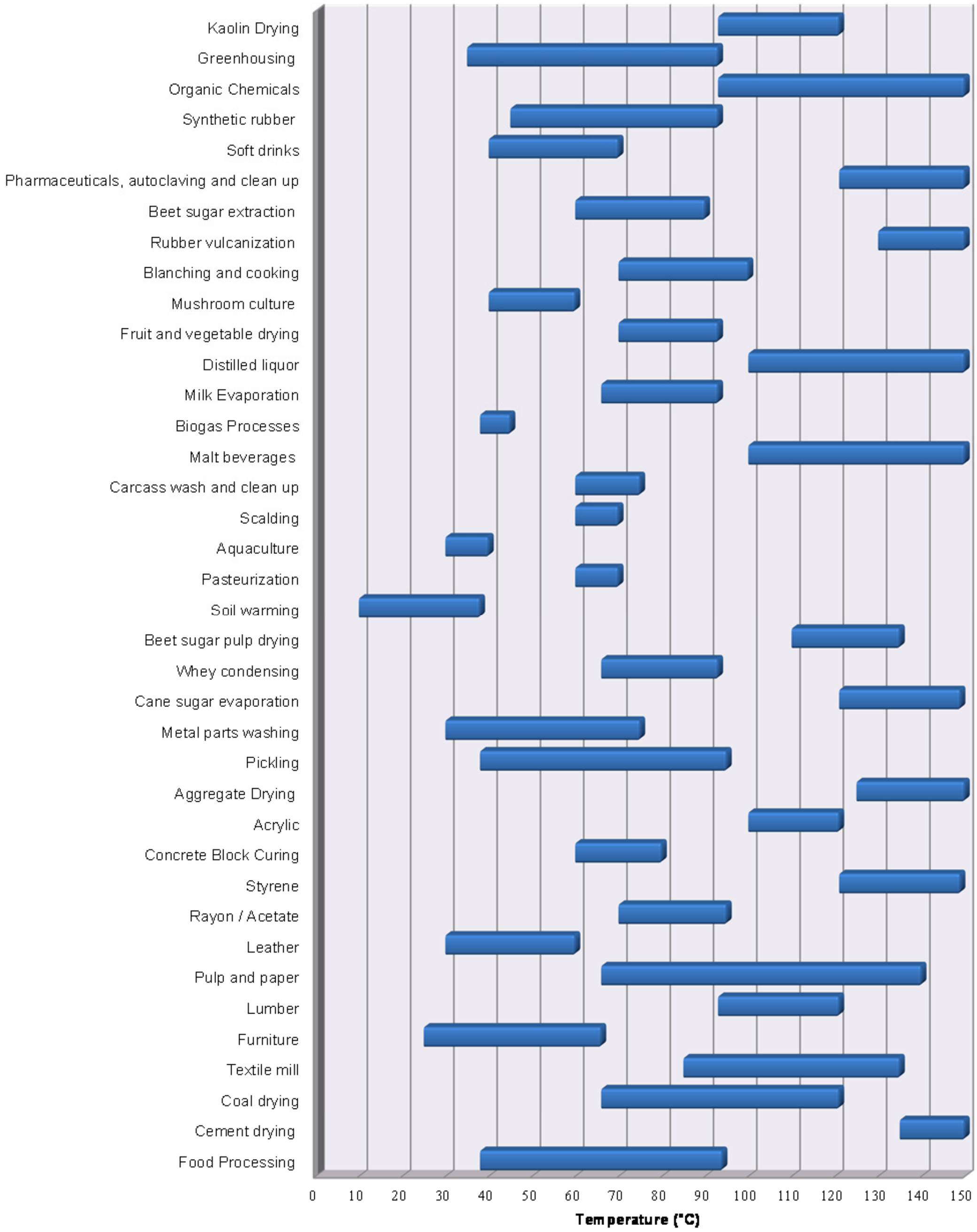


FIGURE 7: Range of temperatures for different industrial processes
Source: Lienau, 2003

In some situations where available geothermal fluid temperatures are lower than those required by the industrial application, the temperatures can be raised by means of integrating thermal systems (boilers, upgrading systems, heat pumps and so on). In designing geothermal energy recovery and utilization systems, alternative possibilities could be considered for various applications. The usual approach for the utilization of geothermal fluid by proposed industries is to match the industry to the available fluids. But here the opposite is proposed; this alternate approach means that it is necessary to develop ways to economically upgrade the quality of existing geothermal fluids. Figure 7 shows application temperature ranges for some industrial uses (Lienau, 2003). The following is a calculation example of a fish drying process:

*Assumptions:*
9600 kg of fish, containing 82% water, are dried to 55% water in a primary dryer and to 15% water in a secondary dryer.

*Calculation:*
During primary drying (40 hours) $x$ kg of water is removed (evaporated):

$$(9600 \text{ kg} \times 0.82 - x) / (9600 \text{ kg} - x) = 0.55; \; x = 5760 \text{ kg}$$

During secondary drying (100 hours) y kg of water is removed (evaporated):

$$(9600 \text{ kg} \times 0.82 - 5760 \text{ kg} - y) / (9600 \text{ kg} - 5760 \text{ kg} - y) = 0.15; \; y = 1807 \text{ kg}$$

*Assumptions:*
A mixture of outside air at 5°C and 80% humidity and return air from the dryer is heated up to 25°C and 45% humidity before it is blown over the product in the dryer.

Outlet air temperature from the dryer is 19°C and the geothermal water used for heating the air is at 70°C inlet temperature and 30°C outlet temperature.

*Calculation:*

Weight of product after primary drying: 9600 kg – 5760 kg = 3840 kg.

Evaporated water per hour: 5760 kg / 40 h = 144 kg/h.

Air flow rate needed: $\dot{m}$ = 144 kg/h / ($x_3 - x_2$) = 144 kg/h / (0.0112 – 0.0088) = 60,000 kg/h or $\dot{V}$ = 60,000 / 1.2 = 50,000 $m^3$/h, where x is the humidity of the air (kg water / kg air) and 2 and 3 refer to the inlet and outlet of the dryer respectively.

Heating requirement: $q$ = 60,000 kg/h × ($i_2 - i_1$) = 60,000 kg/h × (47 – 36) = 660,000 kJ/h, where i is the enthalpy of the air (kJ / kg air) and 1 and 2 refer to the inlet and outlet of the air heater respectively.

Flow rate of hot water needed: $q = m \times c_p \times (T_{in} - T_{out})$.

$c_p$ = specific heat capacity of water = 4.2 kJ/(kg°C).

$m$ = 660,000 kJ/h / [(4.2 kJ/(kg°C) × (70°C – 30°C)] = 3,929 kg/h.

Total quantity of water needed during primary drying is 3,929 kg/h × 40 = 157.2 ton.

### 5.2.3 Bathing pools

In Honduras, as explained before, there are many sites of low-temperature geothermal potential which could be used as a renewable resource for such projects as bathing pools or spas in different places around the country; contributing to health and social benefits alike, e.g. minimizing the effects of aging, promoting better health, to reduce weight, to prevent diseases and other reasons (Lund, 2000).

The design of mechanical systems involving heat transfer, such as direct-use geothermal systems, is heavily influenced by temperature. Temperature difference (delta $T$ or $\Delta T$) is particularly important as it frequently governs feasibility, equipment selection, and flow requirements for the system.

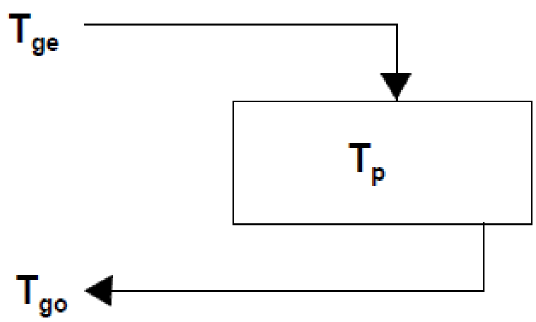


FIGURE 8: Fundamental direct-use temperature differences (Lund, 2011)

Two main temperature differences ($\Delta T$) influence the feasibility, flow requirements, and the design of the heating equipment, as illustrated in Figure 8. The first is the difference between the entering geothermal water ($T_{ge}$) and the process temperature ($T_p$), which determines the feasibility of the system.

The greater the $\Delta T$ the smaller the size and thus, the lower the cost of the heat transfer equipment. The second is the difference between the temperature of the geothermal water entering the system ($T_{ge}$) and leaving the system ($T_{go}$). This $\Delta T$ determines the geothermal water flow rate necessary to provide heat to the system. The greater the $\Delta T$ the smaller the required flow rate. The departing geothermal temperature cannot be lower than the process temperature. The application of some rules is described below for bathing pool heating (Lund, 2011):

| Delta T | Influence |
|---|---|
| $\Delta T_1 = T_{ge} - T_p$ | Feasibility of the system, equipment cost |
| $\Delta T_2 = T_{ge} - T_{go}$ | Geothermal flow rate |

Bathing pool heating is one of the simplest geothermal applications, as it usually uses the geothermal water directly in the pool to provide the required heat demand. This is illustrated in Figure 9. Considering the average of low-temperature hot springs in Honduras, 50°C geothermal water is supplied to heat the pool water to 30°C. Thus, the $\Delta T$ is 20°C, and as an example it is assumed that the flow rate is 10 kg/s. If the supply temperature were instead 40°C, the flow rate would have to be doubled to provide the same amount of energy, four times at 35°C, and eight times at 32.5°C.

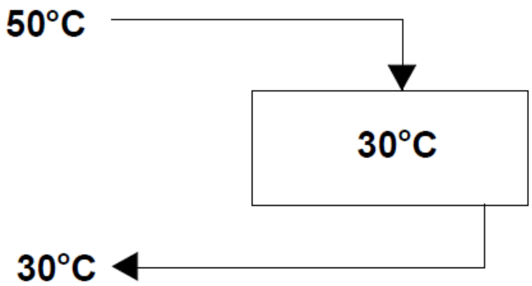

FIGURE 9: Direct pool heating (Lund, 2011)

Flow requirement proportional to $T_{ge} - T_{go}$

At 40°C, flow = 2×
At 35°C, flow = 4×
At 32.5°C, flow = 8×

The heating power (energy supplied in watts) for the example above can be calculated as follows:

W = Flow rate (kg/s) × $\Delta T_1$ (°C) × 4,184 [J/(kg°C) heat capacity of water]

W = 10 kg/s × 20°C × 4,184 J/(kg°C)

Heating power = 837 kW (837,000 J/s)

Sometimes the geothermal water cannot be used directly due to health restrictions. Then a heat exchanger is necessary to heat treated water for the bathing pool. Assuming that the heated water to the pool should be 10°C above the pool temperature, 40°C secondary water would have to be provided to the pool. Using a heat exchanger between the geothermal water and the secondary water; 50°C geothermal water will supply the system as the average temperature of the low-temperature geothermal resources in Honduras (Figure 10).

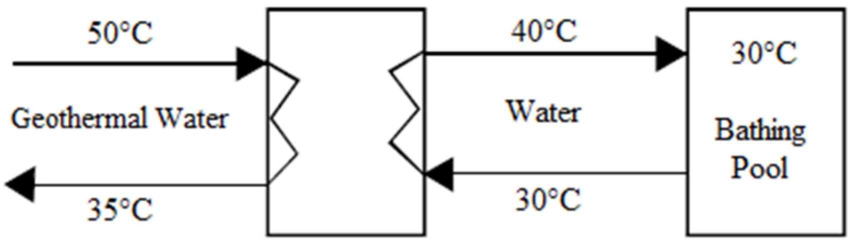

FIGURE 10: Pool heating with heat exchanger (Lund, 2011)

A $\Delta T$ of 5°C is required for heat transfer between the geothermal water and the secondary water return side. Thus, the geothermal water return temperature will be 35°C and the required geothermal water flow rate will increase to 13.33 kg/s (10×20/15 = 13.33 kg/s).

## 6. PROJECT CYCLE / SUCCESSFUL CASES

In Honduras there have been some efforts to develop the geothermal resources; two of these cases are Geoplatanares and Azacualpa Geothermal Projects. Actually those projects are considered the most advanced projects in Honduras for electricity generation. A typical project cycle for a geothermal project is shown in Figure 11.

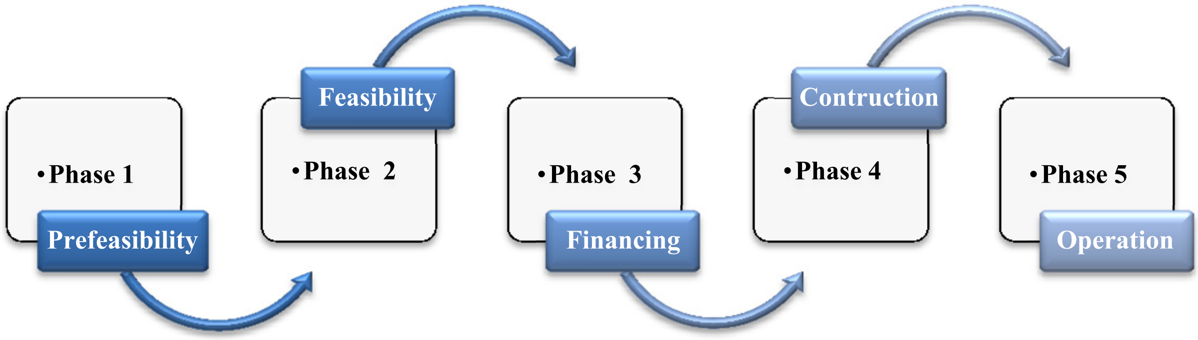


FIGURE 11: Project cycle (Steingrímsson, 2011)

### 6.1 Platanares geothermal project

This project has already finished its feasibility phase and is now in the financing phase. Effort is being made to carry out the operation of this geothermal project, considering that it could be the first geothermal power plant in Honduras.

*Some results of the Platanares geothermal project feasibility study:*
About 100 hot springs and fumaroles have been registered in the Platanares site, covering an area of 5 $km^2$. All springs are located along normal faults, suggesting an intense circulation system. Two reservoirs have been identified in the area. One is at a depth between 450-650 m with a characteristic temperature between 160-165°C and another is at a depth between 1.2-1.5 km with a characteristic temperature in the range of 225-240°C.

The highest concentrations of $CO_2$ were obtained in the central southern area investigated approximately 600 m west of the Quebrada de Agua Caliente and north of Lara River. The anomalies are more significant along the SE-NW area, parallel to the tectonic Platanares guidelines.

With the studies made, it is estimated that annual net production of energy could reach almost 300 GWh, with an installed capacity of 35 MW. This is based on base load operation and a capacity factor of 97% which is very high compared to real values for existing geothermal power plants. Exploration wells have been drilled and were completed at depths from 428 to 679 m (Figure 12).

The energy source is the underground thermal fluid used to activate the power steam turbine which drives a generator directly coupled to the shaft to produce electricity. The application will be continuing as described in the Contract of Purchase and Sale of Energy's National Electricity Company. The storage resource is dependent upon the geometry of the rock containing the thermal fluids (reservoir) and the natural rate of recharge water to infiltrate the geothermal system.

According to the conditions of the field now known, binary cycle turbines for medium temperature geothermal fluid will be installed. In a case where temperature conditions improved and the fluid temperature is higher than 200°C, the possibility of using a single flash turbine system would be considered.

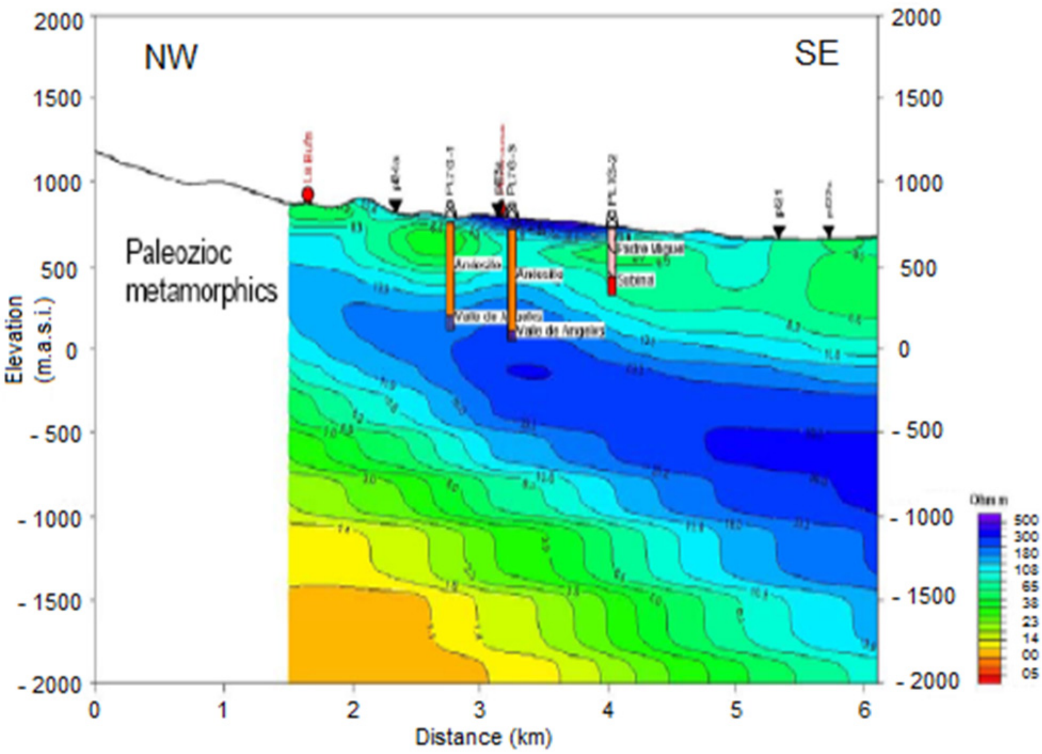


FIGURE 12: Integration of geophysical studies and the gradient wells (Lagos and Gomez, 2010)

### 6.2 Azacualpa geothermal project

This project is still in the feasibility phase; the developing company is now making an effort to carry out all the requirements needed, considering that it could be one of first geothermal power plants in Honduras.

*Some results of Azacualpa Project exploration:*
*Geology:* The Atima limestone formation, which dominates the geology of the area, has a low primary permeability, but a probable secondary permeability exists, which is obvious in the Zacapa fault, where most springs are fed through fractures. The geothermal area is clearly affected by faulting associated with the regional extension of the Caribbean plate and it has always been inferred that the permeability of the thermal area of Azacualpa is directly related to faulting and fracturing (Figure 13).

*Geochemistry:* Using a potassium-magnesium geothermometer in conjunction with a third estimator (called chalcedony mineral silicon), the estimated temperature falls in the range of 160 to 170°C.

In existing studies there is no reference to the proportion of non-condensable gases present in the thermal fluids. These studies indicate that the calculated power is between 15 and 30 MW. It has been concluded that the thermal waters from the reservoir undergo two processes during their ascent to the surface: boiling and shallow-water mixing.

*Geophysics:* The geology is dominated by the Atima limestone formation, which itself has low porosity; however, there is a second porosity from fractures occurring mainly along the Zacapa fault where there is a low resistivity, indicative of the extent of the hot springs. The low resistivity extends over an area of approximately 6 km², but the geothermal field could be extended to a maximum of 27 km² with a maximum reservoir temperature ranging from 160 to 170°C.

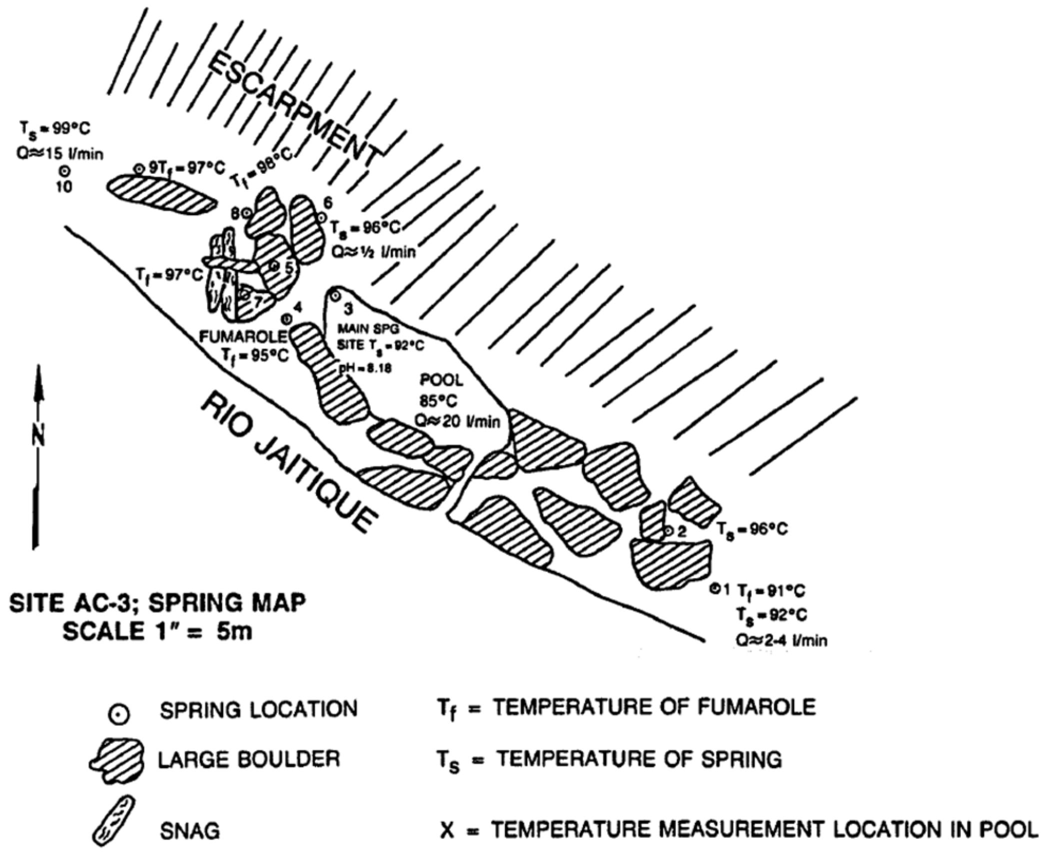


FIGURE 13: Azacualpa geothermal spring site
(Geopower company data bank)

## 7. CONCLUSIONS

1. The manifestations of hot springs on the surface show that Honduras has geothermal potential that could be used for different purposes. The tertiary-quaternary volcanism evident throughout the complex of igneous rocks, outcropping especially in the southern region, and the proximity of this same area to the subduction zone generated by the boundary of the Pacific and Caribbean tectonic plates, illustrate this possibility. The geothermal resources of Honduras have not yet been exploited, but there are different uses such as electricity production and several direct uses that have been mentioned herein which may develop in different parts of the country.

2. 65% of the energy matrix of Honduras currently depends on fossil energy resources and only 35% on renewable resources. Thus, developing the estimated 120 MW geothermal potential for the production of electricity from resources with temperatures ranging from 120 to 200°C and technologies such as binary cycle plants (ORC) will significantly contribute to the country's objectives with respect to increased electricity generation from renewable sources.

3. After considering some climatic aspects of the country like average temperatures and other factors, the market, and the low-temperature resource potential, it has been determined that space cooling by absorption systems is a viable option. Also geothermal energy could be used in several industrial processes and in bathing pools or spas.

4. Honduras currently has legal support to encourage and promote the use of renewable resources for power generation. Within the legal framework are: an energy policy including an exclusive section for the geothermal resource, a Promotion's Law of electricity generation through renewable energy, and the Law of electric subsector.

## 8. RECOMMENDATIONS

1. In Honduras there is a need to strengthen certain areas in the field of geothermal utilization such as the development of technical human resources, technology transfer, international cooperation for the updating of specific studies and research in order to exploit the potential and accelerate geothermal development in the country.
2. This document should be reviewed and updated in order to expand the information contained or go into more detail on a specific topic, especially in the chapter on geothermal utilization with low-temperature resources for direct uses, and getting an appropriate identification and diversified list of possible uses in Honduras, considering the potential and available market.
3. Use should be made of the technologies listed in this document according to the type of resource; also consider an alternative binary power cycle, a so-called Kalina cycle used to generate electricity with medium temperature geothermal resources. Also an absorption system for cooling ($LiBr-H_2O$, $H_2O-NH_3$) should be considered, taking into account the purpose for which it is applied.

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