# Use of Geothermal Energy for Process Heating in Industry

R.E. SALARZA, J.C. MORA, KHIN BO

## Abstract

*This paper deals with the technical and financial feasibility analysis of a specific direct-use geothermal project. The technical analysis involves the matching up of the heat potential of the geothermal resource area (supply side) with the process-steam energy requirements of an industry (demand side). The financial analysis involves the comparison of the annual costs of the geothermal energy system to that of the conventional energy system, and the calculation of the annual savings, the pay-back period, the internal rate of return, and their degree of sensitivity to the various cost factors.*

## Introduction

Geothermal energy is thermal energy which originates from within the earth's crust. Under favorable geological circumstances, a portion of this heat can be extracted and utilized either for power generation or for non-electrical applications.

The technology for direct utilization of geothermal energy is no different from conventional steam or hot water systems except that due consideration must be given to the inherent peculiarities or characteristics of the geothermal streams mainly in the way of materials selection. Thus, technically, geothermal energy can be substituted for most if not all, industrial processes using steam or hot water.

Apart from the technical aspects, the economic viability is obviously a major consideration both in terms of capital investment and operating costs in comparison with a conventional system.

---

R.E. SALARZA is the Dean of the School Engineering Technology, MSU-IIT. He hold an MS Engineering (1989) from the Asian Institute of Technology, Bangkok Thailand. His specialization is in mechanical engineering and the use of energy and pneumatics. JEAN-CLAUDE MORA, PhD, is Salarza's thesis adviser and chairman of the Energy Technology Division at AIT. KHIN BO, PhD, is a faculty member at AIT.

## Applications of Geothermal Energy

**Power Generation:**

Armstead (1983) has listed the number of geothermal power plants worldwide, both in service and planned at the end of 1980. He came up with a grand total of 2585.8 MWe (gross) geothermal capacity in 25 countries. Based on this list, the U.S.A. has the highest capacity with 1100 MWe and the Philippines, second with 894 MWe. He also projected that the installed capacity in year 2000 will be in the range of 8094.3 MWe

In power generation, geothermal steam, instead of steam from a fossil-fuel fired boiler, is used to drive a steam turbine, which in turn generates electricity. Armstead (1983) mentioned several geothermal power generation cycles such as: Indirect condensing, Non-condensing, Straight condensing, Single flash, Double flash and Binary cycles.

**Direct (Non-electrical) Applications:**

Direct heat utilization of geothermal energy maybe classified (Lund et al, 1979) into 3 main categories: industrial processes, space heating and cooling, and agriculture and aquaculture productions.

Summary of direct heat utilization worldwide:

1. Industrial Processes - 200 MWt (megawatt thermal) (2.9%) Typically require the highest temperature, using both steam and superheated water at temperatures up to 150 °C.

2. Space Heating and Cooling - 1,200 MWt (17.4%) Utilizes temperatures in the rage of 66-100 °C.

3. Agriculture and Aquaculture Production - 5,500 Mwt (79.7%) Utilizes the lowest temperatures in the range of 27-82°C

From the above summary, industrial processes accounted for only a meager 2.9% of direct geothermal energy use. This could be due to the high temperature requirements for industrial processes which in turn need more expensive materials and equipment. Also, industrial processes usually rely on fuel-oil for their energy requirements. However, with the spiraling of crude-oil prices, and the increasing awareness that fossil fuels would be depleted in the future, the development and rapid expansion of geothermal energy may become more significant than it is now for industries (Armstead et al, 1980).

It has been stated earlier that geothermal energy is applicable to various industrial processes utilizing steam. Armstead (1983) mentioned several areas such as: chemical industries, food processing and mining and upgrading of minerals.

## Geothermal Energy in the Philippines

### Development for Power Generation:

The Philippine geothermal energy stems from the volcanic origin of the archipelago. The country has a composite geological structure arising from a multi-stage development of volcanic-tectonic events in the past. These geological events have been continuously manifested in the forms of active volcanism and seismic activities occurring along the active blocks of major structural lines which traverse most of the major islands of the Philippines. These structural lines are part of the so-called Pacific circumferential "Belt of Fire."

The extensive volcanisms being localized along the active tectonic blocks have generated regions of high heat flow where a vast number of potentially-rich geothermal resource areas are located. The country has about seventy one (71) known thermal manifestations. Some are shown in Fig. 1.

After the successful completion of the study of the 2.5 KW condensing geothermal pilot plant at Tiwi in 1969, the government launched a systematic and continuing program aimed at harnessing the country's geothermal energy. This led to the development of four geothermal fields within a period of 10 years (1972-1982). These four commercially developed geothermal fields supply the steam requirements for the geothermal power plants with a combined capacity of 894 MWe. Based on NPC records, two of these fields - Tiwi and Mak-Ban supply two generating plants, each with a rated capacity of 330 MWe in the country's largest grid in Luzon. The others two fields - Tongonan and Palimpinon supply two geothermal plants

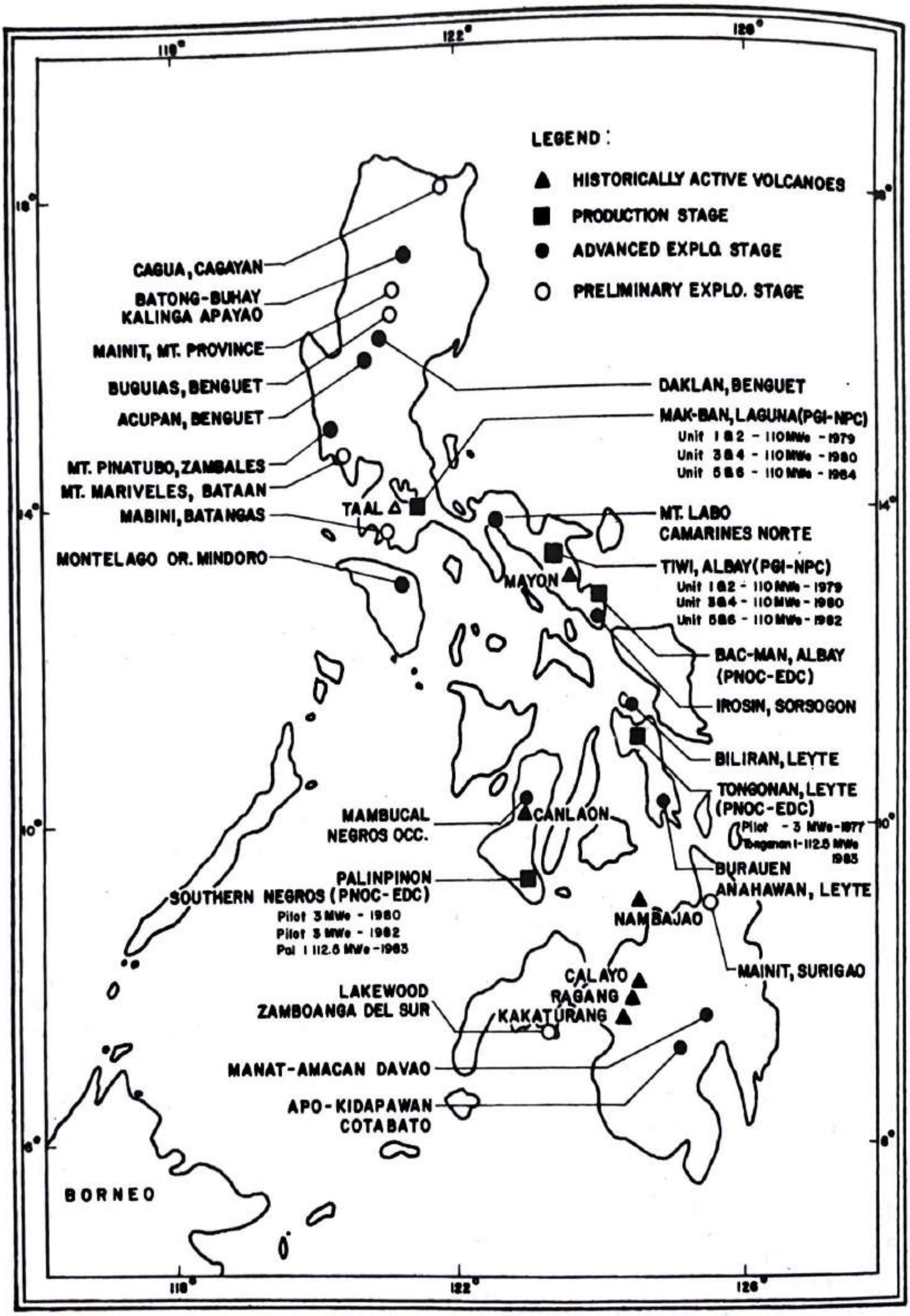


**Figure 1.** Philippines Geothermal Areas

with a combined capacity of 234 MWe in the Visayas. A fifth geothermal field is the Bacon-Manito (Bac-Man) straddling the Albay-Sorsogon provincial boundary in Luzon. This field is intended to support the new 110 MWe Bac-Man plant targeted for commissioning in 1991. The following Tables show the general characteristics of operating geothermal fields in the Philippines (Table 1) and reserves of geothermal prospects (Table 2).

The construction and operation of the four geothermal power plants in the country with a generating capacity of 894 MW has remarkably reduced its oil dependence over the past decade. Based on records from the Office of Energy Affairs (OEA) last year (1988), the four power plants generated 4,842,224 MWh of electricity or an equivalent of 8.070 million BFOE (barrels of fuel-oil-equivalent). At the price of about $16.50 (NPC price) per barrel of oil last year, this amounted to a foreign currency savings of $133 million.

### Past Ventures in Direct Non-electrical Applications:

In a further attempt to substantially reduce the country's dependence on imported oil, an equally significant area is the direct or non-electrical utilization of geothermal energy which has yet to be developed. This is most suitable to industries utilizing low- to moderate temperature process steam generated by boilers which are solely dependent on imported fuel oil. At present, there is no operating plant in the country utilizing geothermal heat for non-electrical applications. Although in the past, the Philippine Institute of Volcanology and Seismology (PHILVOLCS), formerly COMVOL has ventured into direct heat utilization (Roxas, F., 1987). An experimental salt-making plant designed to utilize geothermal steam was installed in 1972 in Tiwi. Encouraged by the success of the pilot plant, the then National Science Development Board (NSDB) and PHILVOLCS put up a semi-commercial salt-making plant. This venture produced over one ton of industrial grade salt per day, until operations ceased in 1984 due to well clogging. The pay-back period was estimated at 3-5 years. The production cost of the venture was approximately Peso 5.00/kg. of salt.

Another non-electrical application of geothermal energy initiated by PHILVOLCS in June 1979 was a fish canning venture. Operations started in the last half of 1983 but stopped in late 1986 due to steam unavailability. The process involved the use of steam pressure cookers specially designed and fabricated for use with geothermal steam. With an output of 400 cans per day, PHILVOLCS production cost using geothermal steam varied between

## APPENDIX

**Table 1**: General Characteristics of Operating Geothermal Fields in the Philippines

| | GEOTHERMAL FIELD: | TIWI | MAK-BAN | TONGONAN | PALIMPINON | BAC-MAN |
|---|---|---|---|---|---|---|
| 1. | Location | Albay | Laguna | Leyte | Negros Or. | Albay |
| 2. | Proponents | NPC & PGI | NPC & PGI | PNOC-EDC | PNOC-EDC | PNOC-EDC |
| 3. | Arrangement Services | Service Contract with PGI | Service Contract with PGI | PNOC-EDC | PNOC-EDC | PNOC-EDC |
| 4. | Financial Assistance | - | OECF of Japan | OECF of Japan | W B Loan | - |
| 5. | Technical Assistance | - | New Zealand Government | New Zealand Government | Philippine Government | - |
| 6. | No. of Wells | 112 | 87 | 52 | 56 | 26 |
| 7. | Estimated Total Well Capacity | 350 MW | 355MW | 413 MW | 246 MW | 74 MW |
| 8. | Estimated Field Potential Available | - | 15,000 MW years | 12,000 to 7,000 MW years | 9,750 MW years | 2,350 MW years |
| 9. | Status | For further development | For further development | For further development | For further development | Under development |
| 10. | User | NPC | NPC | NPC | NPC | NPC (in 1990) |
| 11. | Installed Capacity, Year of Operation | Units 1 & 2 110 MW, 1979<br>Units 3 &4 110 MW, 1980<br>Units 5 & 6 110 MW, 1982<br>**Total:330 MW** | Units 1 & 2 110 MW, 1979<br>Units 3 & 4 110 MW, 1980<br>Units 5 & 6 110 MW, 1984<br>**Total:330 MW** | Pilot Unit 3.0 Mw, 1980<br>Unit 1 112.5 MW, 1983<br>**Total:115.5 MW** | Pilot Unit 3.0 MW, 1980<br>Pilot Unit 2 3.0 MW, 1982<br>Unit 1 112.5 MW, 1982<br>**Total:118.5 MW** | - |

Source: World Bank Energy Sector Report, 1988

**Table 2:** RESERVES OF PHILIPPINE GEOTHERMAL PROSPECTS

| FIELD NAME OR PROSPECT | INSTALLED, | PROVEN, (MW) | PROBABLE, (MW) | POTENTIAL, (MW) | (MW) |
|---|---|---|---|---|---|
| A. LUZON: | | | | | |
| 1. Mak-Ban | 330 | 387 | 440 | 800 | |
| 2. Tiwi, Albay | 330 | | 330 | | 250 |
| 250 | | | | | |
| 3. Bac-Man | - | 140 | 80 | | 220 |
| 4. Batong-Buha | - | 150 | 350 | | 350 |
| 5. Mt. Pinatubo - | - | 200 | | 300 | |
| 6. Irosin-Bulusan - | - | - | 30 | | |
| 7. Mt. Labo | - | - | 400 | | 1,000 |
| 8. Daklan, Benguet - | - | - | 50 | | |
| 9. Buhi-Isarog - | - | 160 | | - | |
| 10.Acupan-Itogon - | - | - | 34 | | |
| 11.Mt. Natib | - | - | | 60 | 160 |
| B. VISAYAS: | | | | | |
| 12.Tongonon | 115.5 | | 400 | 800 | |
| 1,200 | | | | | |
| 13.Palimpinon | 118.5 | | 224 | 283 | 372 |
| 14.Biliran Island - | 7 | | 283 | 372 | |
| 15.Mambucal | - | 1 | 1 | - | |
| 16.Baslay-Dauin - | 1 | 20 | 30 | | |
| 17.Anahawan | - | - | 160 | 160 | |
| 18.Burauen | - | - | 330 | 330 | |
| 19.Bato-Lunas | - | - | 160 | 160 | |
| C. MINDANAO: | | | | | |
| 20.Mt. Apo | - | - | 160 | 160 | |
| 21.Malindog | - | - | 160 | 160 | |
| 22.Amacan | | - | 1 | 916 | 30 |
| TOTAL: | 894 | | 1,641 | 5,313 | 6,168 |
| UNDISCOVERED RESERVES: | 1,000 TO 2,000 | | | | |
| APPROXIMATE TOTAL POTENTIAL: | 8,000 | | | | |

Source: World Bank Energy Sector Report, 1988

P4.20 - P4.54 per can, which is cheaper compared to the prevailing supermarket prices of P6.60 - P7.50 per can of tuna in 1983.

## Makiling-Banahaw (Mak-Ban) Geothermal Resource Area:

One of the objectives of this study is to identify a suitable geothermal resource area for a feasibility study with possible prospects leading to a pilot/demonstration plant for industrial process heating. This feasibility study maybe realized by utilizing the dormant Maibarara fields which is part of the Mak-Ban geothermal contract area of PGI and NPC (see Fig. 2). Mak-Ban actually also includes the Bulalo thermal field which is currently supporting 6 x 55 MWe power plants or a total electricity generating output of 330 MWe.

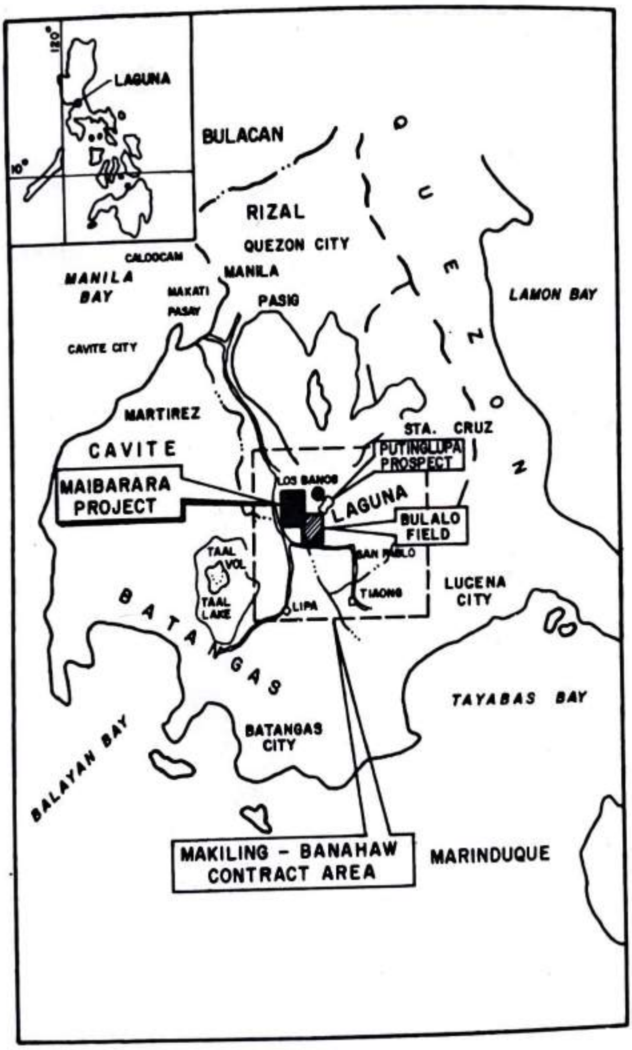


**Figure 2.** Location Map of Mak - Ban Geothermal Contract Area

The Maibarara thermal field is located approximately 8 kms. northwest of the Bulalo field or 60 kms. south of Metro Manila, which is the main commercial and industrial center of the Philippines. Maibarara has eleven existing but unused wells, five of which maybe tapped for industrial process heating. Table 3 gives a detailed description of the characteristics of each well.

Another consideration in favor of the Maibarara fields is the availability of abundant supply of potable water in the area. In the Bulalo geothermal fields, the only supply of water sufficient to support an industrial plant have already been tapped by NPC and PGI for the requirements of their huge cooling towers. Since the industrial plant under study utilizes potable process water at about seven times the amount of finished product it produces, the Maibarara area is strategically suited for its location.

With five productive wells, the Maibarara geothermal field is capable of supplying over 227,273 kg/hr of steam at an average of 0.88 MPa wellhead pressure. PGI reported that with an area of 450 acres enclosing Maibarara's five producing wells, the potential mass-in-place is $10 \times 10^{10}$ kg. With an assumption that only 50% is recoverable, and that 50% of the recoverable portion will be steam, the expected energy generation potential is 250 MW-yr (based on 11,340 kg/hr steam rate). On this basis, PGI evaluated that Maibarara can reasonably sustain a 12 MWe plant for 21 years or a 20 MWe plant for 12 years. Alternatively, it could also be used to supply the combined process steam requirements of the nearby industries amounting to 113,636 to 181,818 kg/hr. as based on a survey conducted by PGI.

## Technical Feasibility of Using Geothermal Energy for Industrial Process Heating

### Link-up Factors:

Direct use projects can vary appreciably in size and capital value depending on the type of the geothermal resource and the application. There may be certain technical and engineering problems and parameters which have to be considered. However, as mentioned in the first part of this study, the technology is available.

In geothermal energy applications, the hot fluid characteristics depend on the resource. The engineer-designer does not enjoy the freedom of choosing them. It can be said that the cost of geothermal fluids is by and

**Table 3.** Flow Characteristics of the Maibarara wells

| WELL NO. | DEPT, m ft. (BOTTOM) | WELL TEMP. °C lb/hr | TWO-PHASE FLOWRATE, kg/hr lb/hr | STEAM FRACTION KG/HR lb/hr | STEAM FLOW Kj/KG BTU/lb | HOT WATER FLOW, - | AVE. ENTHALPY ATELL-HEAD | MW CAPACITY* | DATE COMPLETED | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1,022<br>3,353 | 243.3 | 54,975<br>121,200 | 0.27 | 14,843<br>32,724 | 40,132<br>88,476 | - | 1.42 | 08-13-77 | Not Commercial |
| 2. | 1,676<br>5,500 | - | Dry Hole | - | - | - | - | - | 05-14-79 | Not Productive |
| 3. | 2,980 | 282.2 | 121,868 | 0.37 | 45,041 | 76,827 | 1,519 | 4.32 | 07-20-80 | Productive |
| 4. | 3,062<br>10,045 | - | Dry Hole | - | - | - | - | - | 03-16-81 | Not Productive |
| 5. | 2,563 | 315.6 | 74,843 | 0.49 | 36,373 | 38,170 | 1,763 | 3.85 | 01-16-81 | Productive |
| 6. | 1,981 | 315.6 | 115,212 | 0.73 | 84,105 | 31,107 | 2,249 | 7.07 | 04-09-81 | Productive |
| 7. | 2,249<br>7,970 | - | Dry Hole | - | - | - | - | - | 07-06-81 | Not Productive |
| 8. | 2,195<br>7,203 | - | Dry Hole | - | - | - | - | - | 08-15-81 | Not Productive |
| 9. | 1,679<br>5,510 | 235 | 128,375<br>283,019 | 0.34 | 43,647<br>96,226 | 84,728<br>186,793 | 1,440<br>619 | 4.18 | 05-15-81 | Productive |
| 10. | 2,980<br>9,778 | - | Dry Hole | - | - | - | - | - | 06-07-82 | Not Productive |
| 11. | 2,855<br>9,368 | 315.6 | 71,215<br>157,000 | 0.31 | 22,076<br>48,670 | 49,138<br>108,330 | 1,389<br>597 | 1.95 | 02-19-83 | Productive |
| 79-11SH | 1,608<br>5,275 | 289.9 | 17,335<br>38,217 | 0.9 | 15,601<br>34,395 | 1,734 | - | 1.5<br>3,822 | 10-18-79 | Not Commercial |

* Based on A Steam Usage Rate of 23,000 lb/hr/MWe.
Source: NPC & PGI

large, that of extraction. The important factors that affect the production, and hence the costs of geothermal energy are: well flowrate, resource temperature, distance from consumer, system load factor, disposal of used fluid (reinjection) and cost of capital.

In general, each direct use process has a geothermal energy extraction system which can be characterized as the linking up of up to four engineering functions:

1. Production of geothermal fluid
    - Production wells
    - Well-head equipment & controls
    - Pipelines to heat exchangers

2. Heat extraction for direct-use
    - Heat exchangers
    - Flash units

3. Transmission of geothermal and secondary process fluids
    - Insulated pipelines
    - Circulation pumps

4. Re-injection of geothermal fluids to avoid premature well depletion
    - Re-injection wells
    - Pipelines
    - Re-injection pumps

For a direct-use geothermal system to operate in an efficient manner without wastage of geothermal energy, all these four engineering functions have to be integrated. Items of equipment should not be considered in isolation as they form part of the total plant.

**Scheme for Supplying Geothermal Heat:**

Generally, there are three categories in geothermal energy supply system for non-electrical utilization. These are:

1. Direct heat systems

A supply system where geothermal fluids drawn from the well are utilized directly for non-electrical utilizations (see Fig. 3).

2. Heat exchange systems

Another scheme in which the geothermal fluids transfer heat to another medium, usually secondary process water, via heat exchangers (see Fig.4).

3. Cogeneration system

A scheme wherein the residue or rejected heat from power generating units are recovered for low-temperature non-electrical applications (see Fig. 5).

All three systems can be referred to as "doublet systems" since all the drawn-out geothermal fluids are re-injected back to the reservoir. This practice increases the reservoir projected life and also minimize environmental pollution problems.

**Direct Heat Systems:**

Geothermal fluids are tapped from the well and transmitted directly to the processing facilities. The fluids drawn out from the well-bore are a mixture of steam and water. Depending on the application or user preference, a total flow system or separated fluids from a separator unit may be used for non-electrical applications. These systems are normally used when the geothermal fluid is relatively free of toxic and corrosive elements. A total flow system utilizes the energy from both steam and hot water for simple application. For more complex processes, a steam separation stage may be included which would incur additional capital and operating costs.

**Heat Exchange System:**

In most cases, the fluids coming out from the geothermal wells are difficult to handle and could have an adverse effect on the equipment and the environment due to their corrosive, scaling and toxic characteristics. Table 4 shows that three of the production fields in the Philippines possess these characteristics in addition to having varying amounts of non-conden-

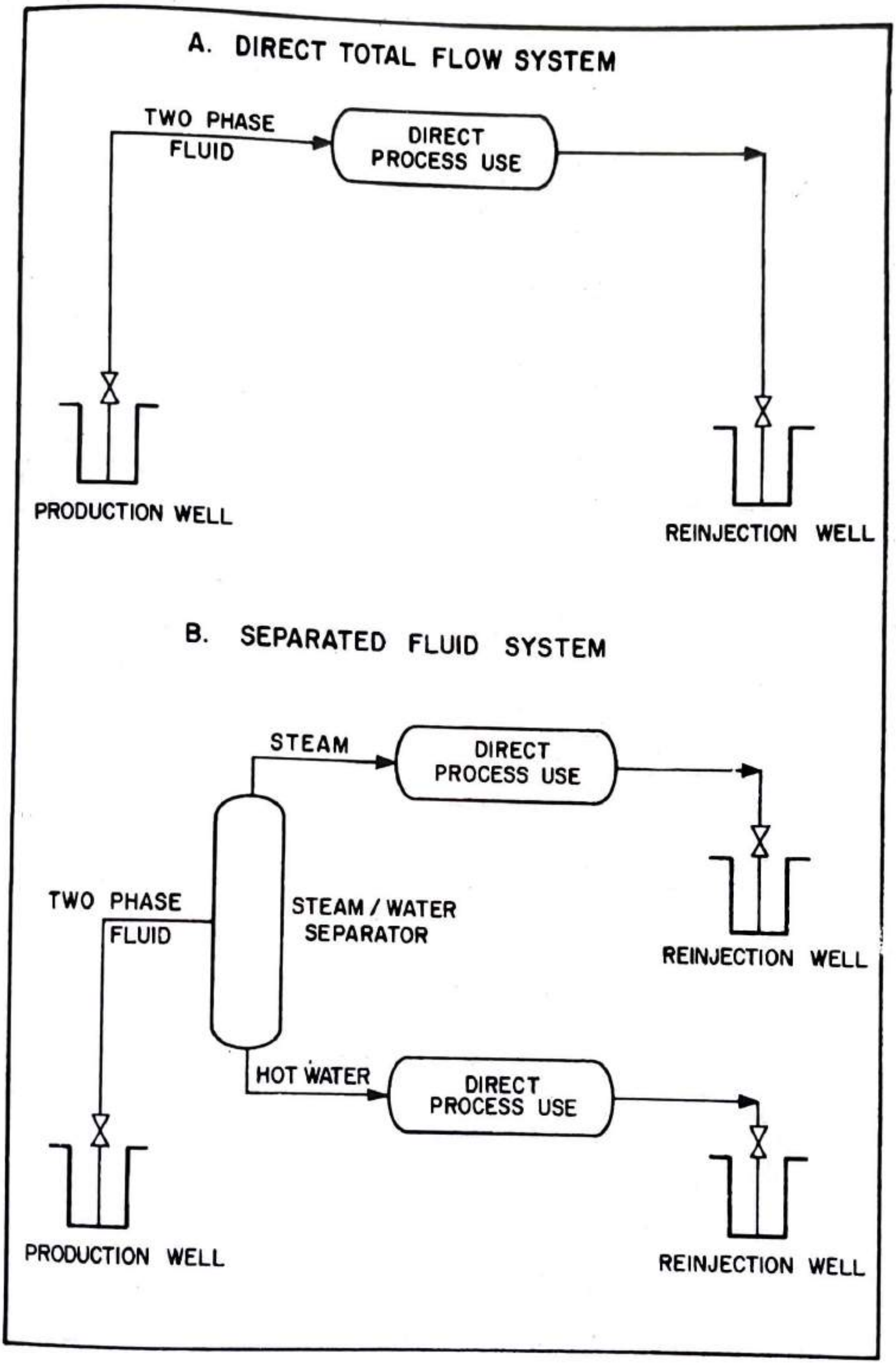


**Figure 3.** Direct Heat System

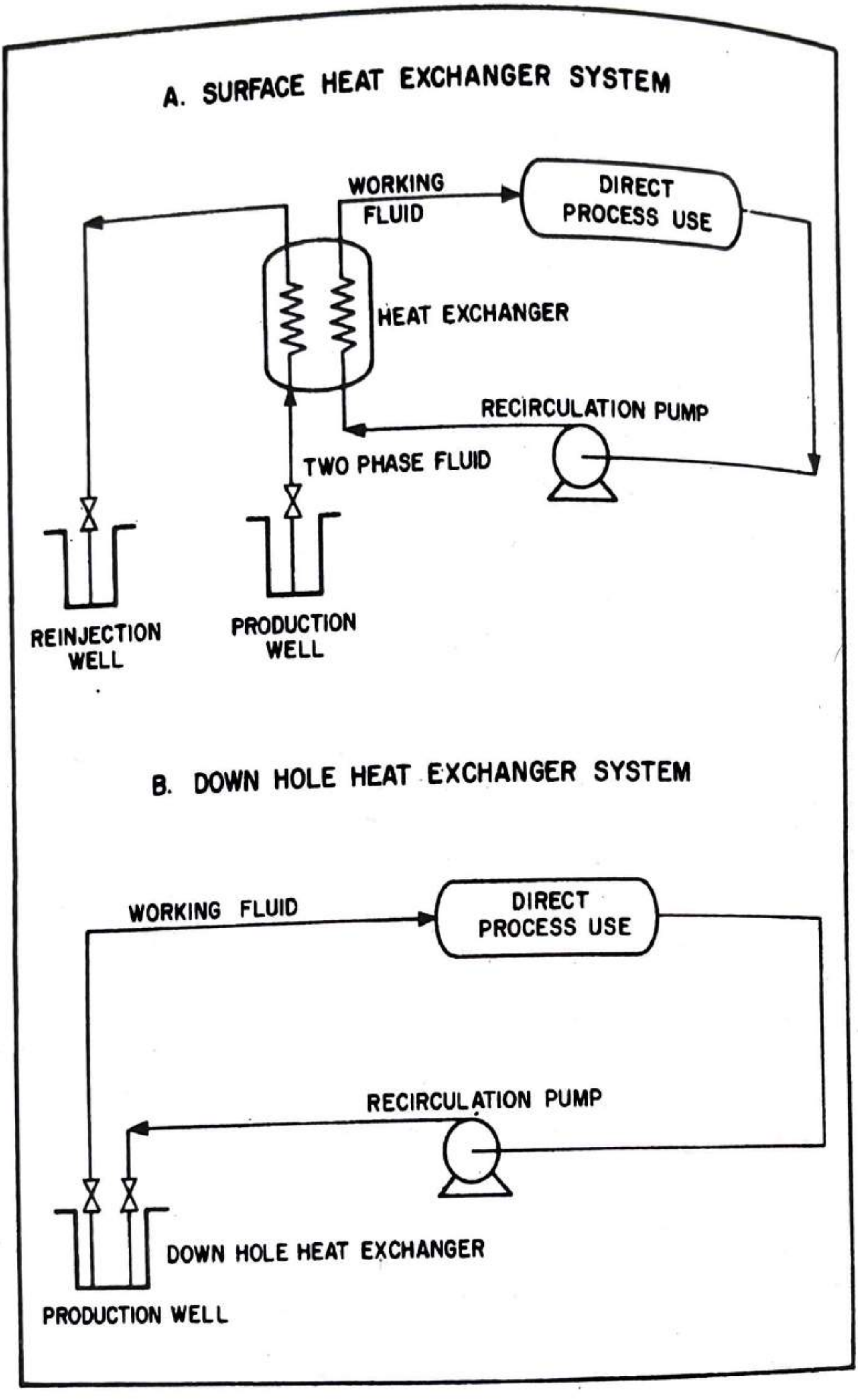


**Figure 4.** Heat Exchanger System

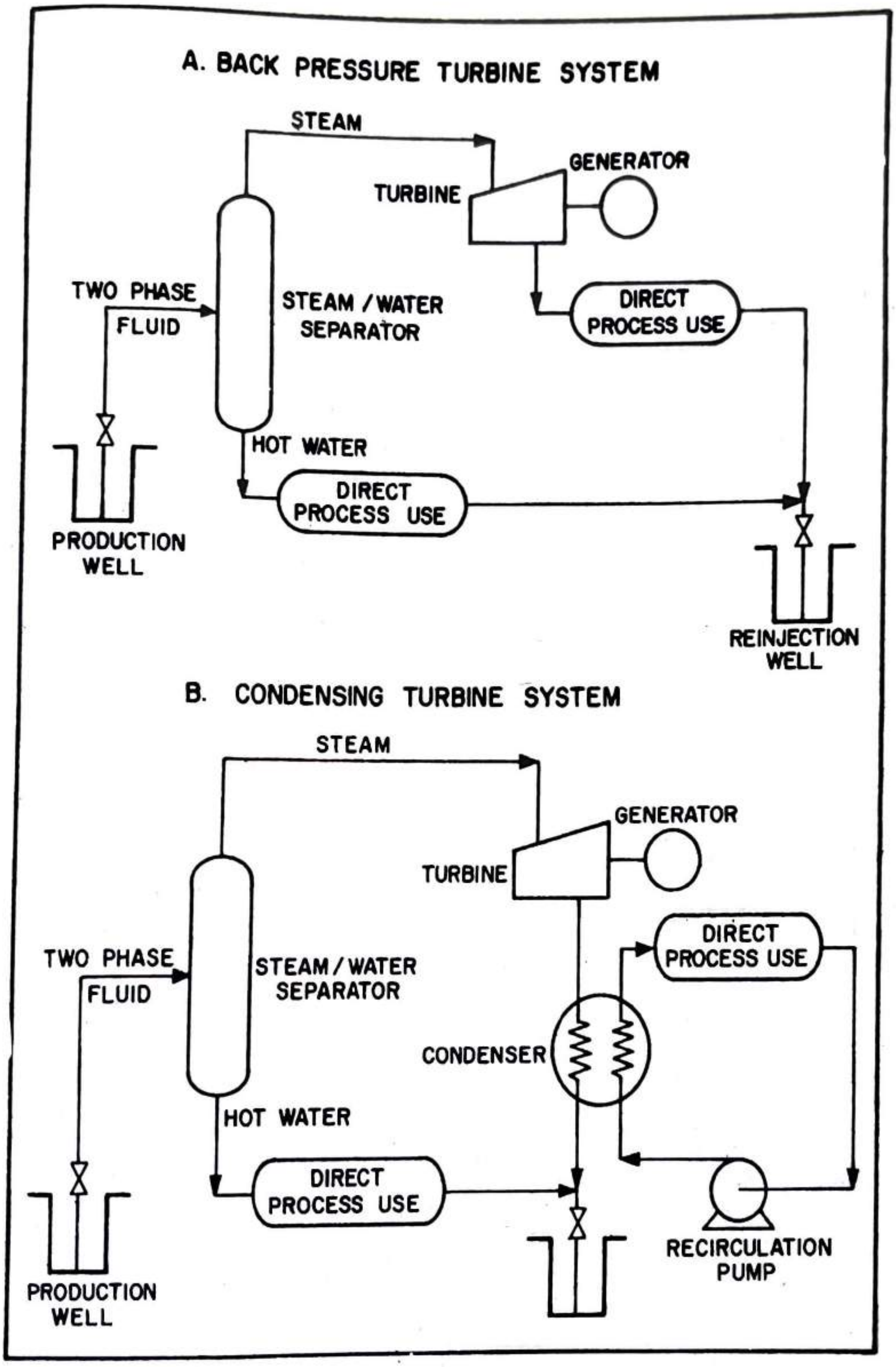


**Figure 5**. Cogeneration System

**Table 4**. Chemical Composition of Geothermal Fields Operated by PGI

| BRINE COMPOSITION, ppm | MAIBARARA | BULALO | TIWI |
|---|---|---|---|
| Sodium | 2,200 | 1,400 | 2,900 |
| Potassium | 650 | 350 | 550 |
| Calcium | 65 | 15 | 70 |
| Magnesium | 1 | 1 | 2 |
| Bicarbonate | 170 | 15 | 110 |
| Silica | 600 | 700 | 450 |
| Chloride | 3,900 | 2,500 | 4,800 |
| Sulfate | 90 | 15 | 120 |
| Boron | 37 | 55 | 56 |
| Non-Condensable Gases (NCG), % weight in steam | 1.75 | 0.85 | 3.00 |
| Ph | 7.2 | 6.9 | 5.7 |

Source : PGI

sable gases. To handle such corrosive fluids for direct process applications, the use of heat exchangers is imperative. The geothermal fluids extracted from the production well are passed through heat exchangers to transmit heat to the working fluid, such as water. This is to restrict the corrosive effects of the geothermal fluids on the primary (geothermal) loop, and to avoid any contamination of the end-product by the geothermal fluid.

**Cogeneration Systems:**

In these systems, separated geothermal fluids are utilized for direct process either with the aid of heat exchangers or direct transmission of heat to the process. There are two possible configurations for these systems. One is applied on a Back Pressure Turbine System and the other on a Condensing Turbine System. In both cases, hot water from the 2-phase separator may be used for non-electrical processing. While the steam in a Back Pressure Turbine System can be used directly, the fluid from the condensing Turbine system undergoes a heat exchange process with another medium.

The salient feature of a cogeneration system is its economic advantage. Recovering heat from the power station's waste streams does not only optimize the exploitation of the reservoir, but more importantly, converts downstream residue to generate additional source of revenue which complement the investment recovery of the geothermal field.

**Choice of the Supply System:**

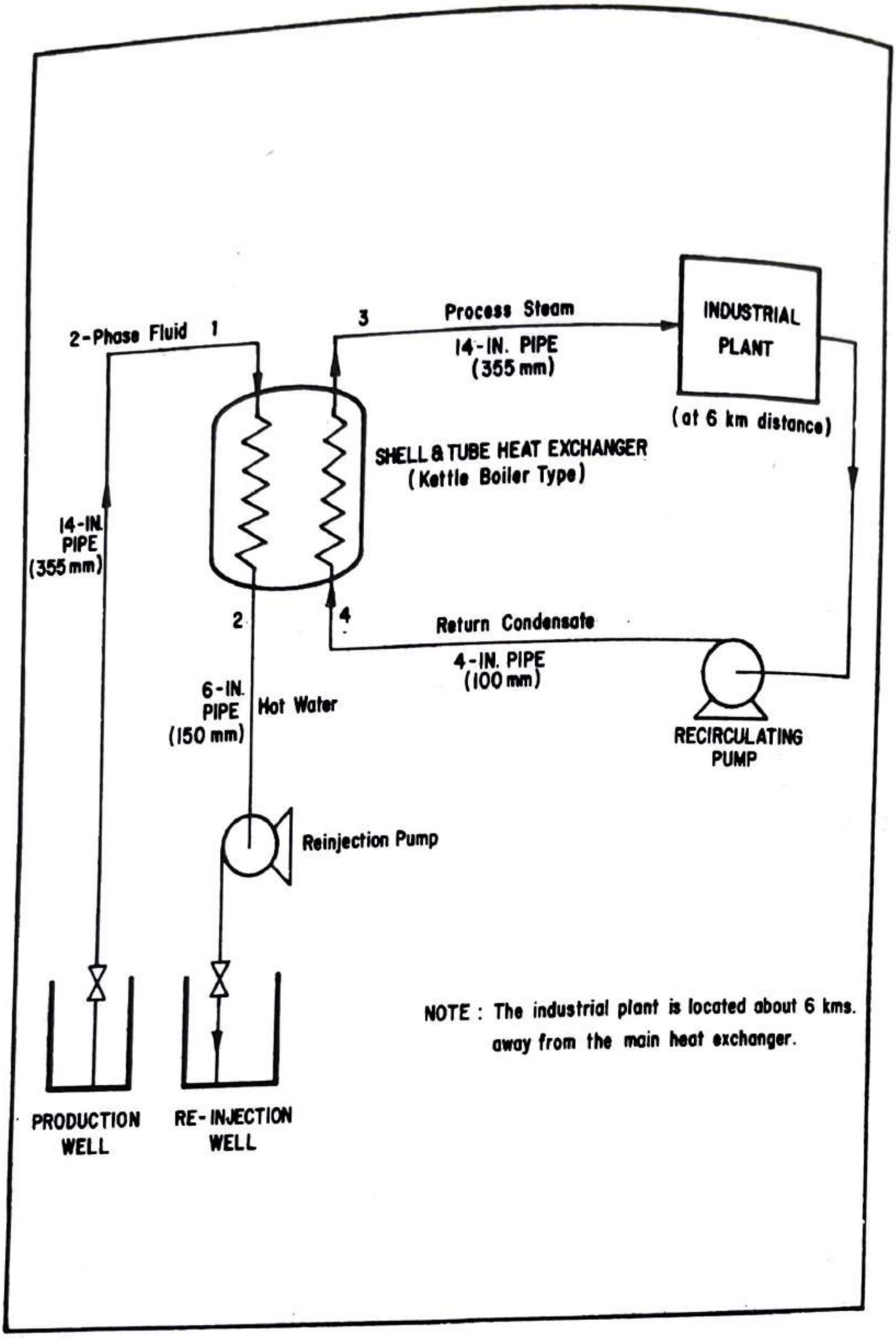
After considering the options, constraints, and other parameters of currently available technologies, the most desirable of the energy supply systems for this study is the surface heat exchanger system. Fig. 6 is a schematic diagram of the stream generation and utilization which will be adapted in the engineering design and cost estimates for this particular process heating application. The reasons for choosing this system can be enumerated as follows:

1. The common maintenance problems inherent in the geothermal fluid handling operations can be confined within the primary (geothermal) side, i.e., fluid production, heat exchange and re-injection.

2. The required re-injection temperature, i.e., 160°C minimum, can be easily met without affecting the energy demand of the industrial plant. Based on studies of the geothermal fluid characteristics of the Maibarara field, the minimum temperature required for efficient reinjection of the geothermal fluids is at 160°C.

3. The primary side can be run at constant flow while the secondary loop independently takes care of the system variations in the heat demand.

4. The total or two-phase flow utilization of geothermal fluid, wherein the latent heat of both hot water and steam is utilized, is more efficient than the single flash steam system, wherein only the latent heat of the separated steam is utilized. Similarly, the size of the heat exchanger is smaller compared to other heat exchangers operating at the same well-head pressure.



NOTE : The industrial plant is located about 6 kms. away from the main heat exchanger.

**Figure 6.** Schematic Diagram of Steam Generation & Utilization

The direct heat system cannot be adapted to the particular plant under consideration because of the nature of its product. It is absolutely necessary that no contamination by the geothermal fluids occur to the product during the various processes involved. Only clean, culinary steam may be used.

The cogeneration system could have been an ideal option for the rational use of energy available. The concept of cascaded utilization to "squeeze the last drop of energy" is very applicable to this system. However, there are at least two reasons why this system cannot be adapted to the existing geothermal plants in the Mak-Ban area or for the other three geothermal plants as well:

1. The existing condenser is a direct contact or spray type where cooling water fed from the top of the condenser shell falls down through several cooling water trays which are provided with numerous holes to effect a fine spray of cooling water for maximum contact with the steam coming into the condenser directly from the turbine. With this set-up, it is not possible to put a heat exchanger to recover the heat from the steam coming in the condenser.

2. To change the existing turbine-condenser set-up would necessitate a major plant revamp at considerable capital expenditure and disruption of power generation.

**Design Basis for the Major Link-up Equipment:**

The major equipment involved in the link-up are the following: Main Heat Exchanger, Recirculating Pumps and Piping System. The industrial plant will also be using an Absorption Refrigeration System driven by geothermal heat. These three major equipment must be designed to suit the requirements of both the geothermal resource (supply side) and the industrial plant (demand side).

The source of geothermal heat may be taken from Maibarara Well No. 6 which has a well-head temperature and pressure of 194°C and 1.37 MPa, respectively, a two-phase flowrate of 115, 212 Kg/hr. and an average well-head enthalpy of 2,243 kJ/kg.

On the other hand, the industrial plant has steam requirement at saturated temperatures of 180°C at the main heat exchanger, or 130°C at the plant site located six kilometers away, with a flowrate of 59,000 kg/hr. and with an average enthalpy of 2, 778 kJ/kg.

## Main Heat Exchanger:

The shell-and-tube kettle boiler type is deemed as the most appropriate type for the main heat exchanger. This type of heat exchanger has been proven to be successful in generating steam from geothermal heat in the operations of the Tasman Pulp & Paper Co. in Kawerau, New Zealand. The thermal duty of the heat exchanger (refer to Fig. 7) is to generate saturated steam at 180°C from saturated water at say, 30°C (clean process fluid loop). The heat input from the two-phase geothermal fluid at the well-head is at 194°C and the hot geothermal water output is at 160°C.

The basic equations used in the design of the shell-and-tube heat exchanger are given below. For a two-phase flow:

$$Q = m\,[C_p\,dT\ (1\text{-}X) + dH\,(X)] \tag{1}$$

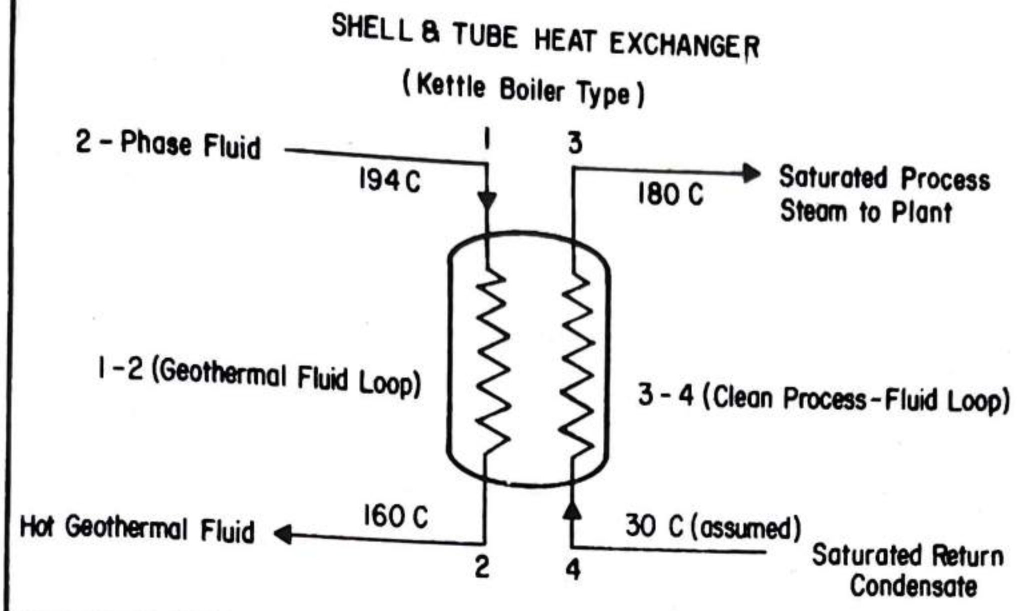
where $Q$ = total heat duty, kW
$m$ = massflowrate, kg/s
$C_p$ = specific heat at constant pressure, kJ/kg°C
$dT$ = inlet and outlet temperature difference, °C
$X$ = dryness factor, %
$dH$ = enthalpy difference, kJ/Kg
$= h_g - h_f$
$h_g$ = vapor enthalpy, kJ/kg
$h_f$ = liquid enthalpy, kJ/kg

Also, the heat duty Q can be expressed in another form:

$$Q = U\ A_T\ dT_e \tag{2}$$

where $U$ = overall heat transfer coefficient, $W/m^2\ °C$
$A_T$ = total heat transfer area, $m^2$

$dT_e$ = effective temperature difference between primary and secondary fluids, °C



| POINT NO. | DESCRIPTION | ENTHALPY, kJ/kg (BTU/lb) | FLOWRATE kg/sec (lb/hr) | TEMPERATURE °C (°F) | PRESSURE MPa (psia) |
|---|---|---|---|---|---|
| 1 | 2- phase geothermal fluid from well at 75% steam fraction | 2,243 (967) | 32 (254,000) | 194 (381) | 1.37 (199) |
| 2 | Hot geothermal fluid to reinjection well | 676 (291) | 32 (254,000) | 160 (320) | 0.62 (90) |
| 3 | Process steam to industrial user for brewing, bottling, and fermenting | 2,778 (1,197) | 16.4 (130,000) | 180 (356) | 1.002 (145) |
| 4 | Return Condensate from industrial processes | 126 (54) | 16.4 (130,000) | assumed at 30 C | 0.004 (0.58) |

Figure 7. Heat Exchanger Flow Streems

Base on a preliminary calculation, the heat duty Q is equal to 40 MWt., the number of tubes equals 60 and the total heat transfer area $A_T$ is equivalent to 33 $m^2$.

**Piping System:**

The piping system connecting the whole set-up maybe sized by manual computation or by computer. Using the computer software employed by the Philippine National Oil Company - Energy Development Corporation (PNOC-EDC) in Manila, and based on the assumption that the industrial plant is located about 6 kms. away from the Maibarara geothermal resource area, the following pipe specifications are summarized in Table 5.

In order to recirculate through the heat exchanger the clean, secondary process steam which condenses through the various processes in the industrial plant, condensate pumps are needed. Two 45-hp pumps with a combined capacity of 59,000 kg/hr. will be required.

**Table 5.** Summary of Pipe Line Specifications

| PIPELINE | FLOWSTREAM | PIPE DIAMETER, mm (in.) | FRICTION LOSS, bar/100 m (psi/100 ft) |
|---|---|---|---|
| Production Well to Heat Exchanger | 2-Phase | 355<br>(14) | 0.387<br>(1.71) |
| Heat Exchanger to Reinjection Well | Hot Water | 150<br>(6) | 0.177<br>(0.79) |
| Heat Exchanger to Industrial Plant | Process Steam | 355<br>(14) | 0.092<br>(0.404) |
| Industrial Plant to Heat Exchanger | Condensate | 100<br>(4) | 0.25<br>(1.12) |

## Absorption Refrigeration System:

The refrigeration requirements of 0.15 - 0.18 tons of refrigeration (TOR) per unit product output of the industrial plant can be accomplished by using an aqua-ammonia absorption system (see Fig. 8), with an evaporator temperature of -5°C. The utilities for a single stage aqua-ammonia has the following specifications for an evaporator temperature of -5°C:

- steam pressure : 2.04 bar
- steam saturation temperature : 112°C
- generator heat requirement : 1.855 kJ/S/kW
- generator steam flow rate : 3.0 kg/hr/kW
- water rate at condenser & absorber : 0.256 $m^3$/hr/kW

Based on the above figures, the following specifications of the absorption refrigeration system can be summarized as follows:

1. Absorption-Refrigeration Unit : Water-Ammonia Type
2. Plant Refrigeration Load : 0.15 - 0.18 Tons of Refrigeration (TOR) per hectoliters knock-out wort per day
3. System Heat Load : 7.59 MW
4. Evaporator :
    Temperature : -5.°C
    Saturation Pressure : 3.55 bar

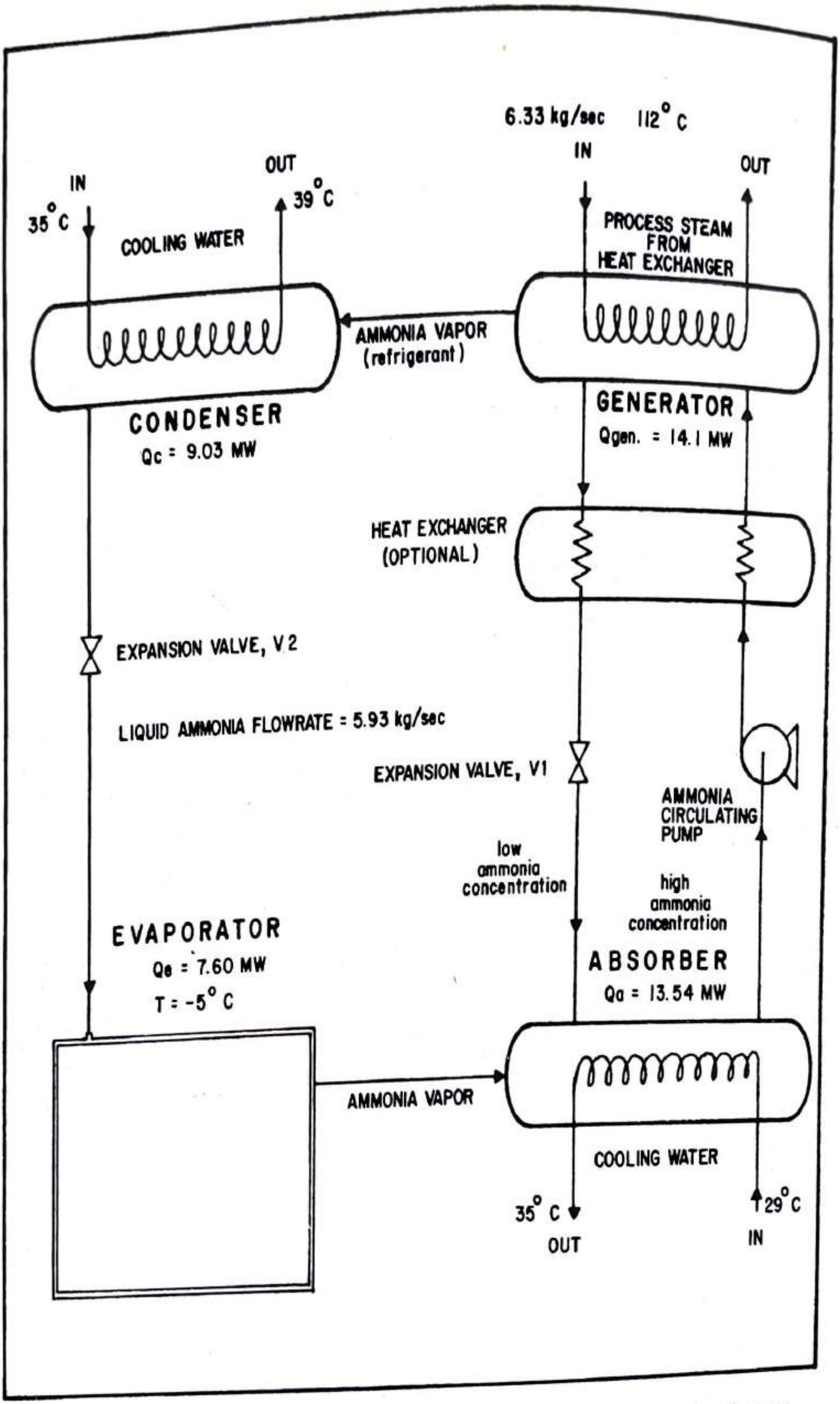


**Figure 8.** Schematic Diagram of Ammonia - Water Absorption Refrigeration System

5. Absorber :
    - Cooling Water In : 29°C
    - Cooling Water Out : 35°C
    - Heat Released : 13.54 MW
6. Generator :
    - Process Steam Flowrate : 6.33 kg/sec
    - Steam Temperature : 112°C
    - Steam Pressure : 2.04 bar
    - Total Heat Added : 14.07 MW
7. Condenser :
    - Cooling Water In : 35°C
    - Cooling Water Out : 39°C
    - Total Heat Released : 14.07 MW
8. Cooling Tower :
    - Cooling Water Flowrate : 540 kg/s

## Financial Feasibility of Direct Utilization of Geothermal Energy for Industrial Heating

### Evaluation Methodology:

Once the size of the resource and the compatibility of its temperature and potential flowrates with the direct-use application have been established, an analysis must be made on the financial viability of the type of application envisaged. The question on financial viability is actually of a two-fold nature. First, is geothermal energy financially attractive relative to other energy sources; that is, is it cheaper than conventional energy? Second, is geothermal energy financially attractive relative to other forms of investments; that is, are the pay-back period (PBP) and the rate of internal return (IRR) on a geothermal investment favorable compared to other investments? These questions mean that the geothermal retrofit or the new installation must guarantee sufficient savings or revenues to justify the amount of capital investment necessary to bring the project on-line.

Life-cycle cost analysis is the method generally used to determine the financial feasibility of the geothermal project. This analysis combines all the techniques of projecting and evaluating total systems costs over the expected lifetime of the project. These costs include capital investments, annual cost of operating and maintaining the system, financing costs, taxes and insurance.

The financial viability of the geothermal option must also be assessed on the basis of cost comparison with a system operating on conventional energy. The capital investment for the latter must thus, also be evaluated including maintenance and operation. These costs would obviously include the cost of fuel which, in the conventional energy design weights very heavily indeed on the final cost of the thermal energy produced. Upon completion of all these forecast flows for the economic life of each system, the geothermal costs will be subtracted from the conventional system costs to arrive at the annual savings occurring in each year of operation.

These savings generated through conversion or retrofitting to geothermal energy will be evaluated just like some revenue from an ordinary investment. These savings may also be available for spending. The geothermal system is expected to operate over a span of say, 20 years. By escalating conventional fuel, electricity, and maintenance costs and the savings derived at some assumed growth rate over the economic life of the project, we can determine the pay-back period (PBP) and the rate of return on investments (IRR).

## Cost of Conventional Energy System:

The industrial plant under consideration uses the conventional boiler system fueled by Bunker C fuel-oil to generate clean process steam for its processes. It also consumes electrical energy for running the compressor of its vapor compression refrigeration systems.

The approximate consumption of fuel oil and electricity per month is 1.9 million liters-of-oil equivalent (LOE). At an average fuel-oil price of P1.9809 (pesos) per liter, the total energy cost per year at 82% load factor is equal to P36.6 M (million). This is the amount which the geothermal system seeks to avoid by replacing the boiler system and the vapor-compression system with an appropriate heat exchanger system and an ammonia water absorption refrigeration system, respectively.

The total capital investment for the steam generating system and ammonia vapor compression refrigeration system is equal to P 92.6 M (see Table 6 for breakdown of costs). The steam generating system includes an imported Babcock Hitachi steam boiler, which has a total equivalent cost (import cost plus local cost) of P44.2M. The refrigeration system which has a combined capacity rating of 1,800 TOR or tons of refrigeration (3 by 600 TOR) includes ammonia compressors, condensers, receivers, pumps, etc. which has a total equivalent cost equal to P48.4 M.

Other cost factors are: annual maintenance costs (including depreciation cost, taxes, insurances) and annual capital recovery cost. Annual maintenance costs are assumed at 1-3% of capital costs, while annual capital recovery costs are computed based on an interest rate of 13.338% (IMF rate for private sector) and a loan period of 5 years. Total annual costs amount to P65.9 M.

## Cost of Geothermal Energy System:

For the same plant, the cost estimates done for the proposed geothermal system are based on either actual figures of existing geothermal power plants or studies conducted by National Power Corporation (NPC), Philippine Geothermal, Inc. (PGI) and the Philippine National Oil Company-Energy Development Corporation (PNOC-EDC).

The total investment costs of the geothermal system is equal to P59.7M covering the costs for: the energy source and infrastructures (P28.6 M), the fluid handling and distribution system (P15.2 M), the ammonia-water absorption refrigeration system (P8.1 M), and overheads (P7.8 M).

The total annual costs add up to P82.8 which include a yearly sunk development cost of P39.4 M; electricity consumption for pumps and absorption refrigeration units; and capital recovery costs based on interest rate of 11.51% (IMF rate for gov't. sector) and a loan period of 5 years. If this annual charge due to sunk cost is not to be included, the total annual costs amount to only P43.3 M.

## Cost Comparison Between the Two Systems:

The cost of energy per gigajoule (GJ) is the total annual costs divided by the annual heat consumed (see Table 6 for summary of cost computations). A comparison of total annual costs for both energy system projected for 21 years is appended in Fig. 9.

**Table 6.** Summary Cost Estimates for Both Energy Systems (Cost in P 000's)

| ITEM | CONVENTIONAL ENERGY | GEOTHERMAL ENERGY |
|---|---|---|
| 1. Investment Costs | 92,596 | 59,718 |
| 2. Annual Repair & Maint. Cost | 2,778 | 25,693 |
| 3. Running Cost (Fuel & Electricity) | 36,567 | 1,271 |
| 4. Annual Capital Recovery Cost | 26,547 | 16,363 |
| 5. Annual Repayment to PGI Sunk Cost | - | 39,455 |
| 6. Total O & M Annual Costs (2+3+4+5) | 65,892 | 82,782<br>(with PGI Sunk Cost) |
| 7. Total Energy Supplied, x $10^6$ GJ/yr | 0.998 | 1.630 |
| 8. Cost of Energy per gigajoule (GJ) | 66.02 ($3.14) | 50.79 ($2.42)<br>With PGI Sunk Cost)<br>26.58 ($1.27)<br>(w/out PGI Sunk Cost) |

Notes:

Item 4: a = p x (CRF, i%, n) where $\text{CRF} = \dfrac{i(1+i)^n}{(1+i)^n - 1}$

= P92.596 M x (CRF, 13338%, 5 yrs.)
= P92.596 M x 0.2867
= P26.547 M for conventional energy

and,

= P59.718 M x (CRF, 11.509%, 5 yrs.)
= P59.718 M x 0.274
= P16.363 M for geothermal energy

Item 7: $Q_b$ = 2778 Kj/kg x 36287 kg/hr x 300 days/yr x 24 hr/day
= $0.73 \times 10^6$ GJ/yr x 80%
$Q_f$ = $0.91 \times 10^6$ GJ/yr
$Q_e$ = 2518932 kWh/mo. x 3600 kJ/kWh x 12 mo./yr. x 0.82
= $0.089 \times 10^6$ GJ/yr
$Q_t$ = $0.91 + 0.089 = 1.0 \times 10^6$ GJ/yr for conventional energy

and,

$Q_g$ = 2243 kJ/kg x 100800 kg/hr x 24 hr/day x 300 days/yr
= $1.63 \times 10^6$ GJ/yr for geothermal energy

Item 1 : Investment Cost for Conventional Energy System:

a. steam boiler - P28.2 M
b. fuel day tank, feedwater tank - P0.95 M
c. boiler accessories - P9.489 M
d. electricals, instrumentation - P2.795 M
e. civil works - P0.408 M
f. fuel storage (1 mil. liters) - P2.268 M
g. $NH_3$ vapor-compression refrigeration system with imported cost of P28.96 M and local portion of P19.53 M.

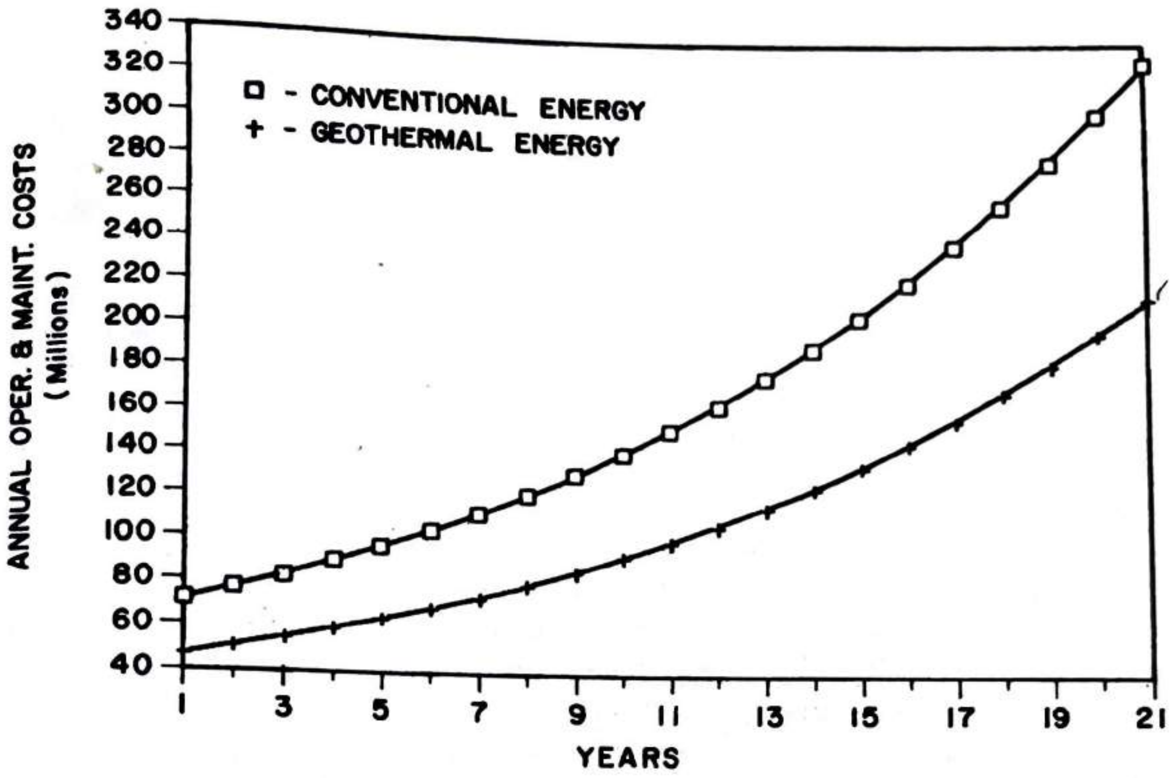


**Figure 9.** Annual Cost Comparison

Based on the flow, characteristics of Maibarara Well no. 6, the geothermal heat $Q_g$, supplied per year assuming 300 days per year operation or a load factor of 82% is equal to $1.643 \times 10^6$ GJ/yr. Based on the cost computations that the total annual costs for the geothermal system is P82.8 M if the NPC/PGI sunk cost recovery is included or P43.3 M per year if it is not included, the cost of geothermal heat $C_g$ is equal to P50.66 or US $2.41 per GJ (with NPC/PGI sunk cost) and P26.52 or US $1.26 per GJ (without NPC/PGI sunk cost).

On the other hand, the industrial plant under consideration has saturated boiler-steam supply of 36,289 kg/hr (or 80,000 lb/hr) at 180°C. From saturated steam tables, the enthalpy is 2,778 kJ/kg. Therefore, the heat supplied from boiler-steam $Q_b$ per year assuming 300 days per year operation or at 82% load factor, is equal to $0.73 \times 10^6$ GJ/yr. Assuming 80% conversion efficiency of the boiler system, the heat supplied by the fuel oil $Q_f$ is $0.91 \times 10^6$ GJ/yr.

The industrial plant also consumes electricity for its refrigeration and chilling requirements. The average electricity consumption per month is 2.52 GWh. Based on this consumption, the energy supplied by electricity Qe per year at 82% load factor is 0.089 x $10^6$ GJ/yr. Therefore, the total energy supplied per year $Q_t$ is the sum of $Q_f$ and $Q_e$ or equal to 0.999 or 1.0 x $10^6$ GJ/yr. With an annual costs of P65.9 M, the cost of conventional energy $C_c$ is P66 or US $3.14 per GJ.

On a per GJ basis, the cost of geothermal energy system is cheaper compared to that of the conventional energy system by 60% or P39.5 (US $1.88) without the PGI sunk cost, and by 23% or P15.3 (US $0.73) with the sunk cost. It should be noted however, that if the PGI/NPC sunk cost is included, the unit cost of geothermal energy is not far behind to that of the conventional energy. This observation has some implications regarding the issue on the recovery of the sunk development cost.

One way of resolving this issue of the Maibarara sunk development cost is to treat it as the Philippine government's share if and when international or outside funding sources such as the Asian Development Bank (ADB), or the French Agency for Energy Management (AFME), are available for the development and utilization of the said geothermal resource area, e.g. setting up a pilot or demonstration plant for feasibility study. After the study phase, any third party developer interested in utilizing the available geothermal energy for industrial applications may be relieved of the "duty" of paying the sunk cost.

The next important question is whether or not the investment for the geothermal system financially attractive relative to other energy investments. In this particular study, the basis of comparison are the minimum rates of return set by PNOC-EDC for such projects, namely: an IRR of 14% and PBP of up to 4 years. In order to estimate the PBP and the IRR, it is necessary to determine the savings derived from investing in the geothermal system. The real savings derived from the geothermal investment is equal to the value of the conventional energy costs avoided minus the O & M costs incurred in running the geothermal project, or;

$$S_G = E_c - (O \& M)_G$$

where:

$S_G$ = annual savings due to the geothermal system
$E_c$ = value of conventional energy (cost avoided), P/yr

(O & M) = operation and maintenance cost of the geothermal project, P/yr

Based on the foregoing cost analysis, several scenarios are considered:

Scenario I : Compares the annual costs of the two systems only in terms of maintenance and fuel/electricity costs, excluding all other annual costs (see Table 7).

Scenario II : Compares the annual costs of the two systems in terms of maintenance and operating costs including annual capital recovery cost, but excluding PGI sunk cost for the geothermal option (see Table 8 and Fig. 9).

Scenario III : Compares the annual costs of the two systems when all annual costs, including PGI sunk costs are considered.

Referring to Table 7, the savings derived for Scenario I is:

$$S_G = \text{P36.567 M} - \text{P26.964 M} = \text{P9.603 M per year}$$

For Scenario II (Table 8) the savings amounted to:

$$S_G = \text{P65.892 M} - \text{P43,327 M} = \text{P22.565 M per year}$$

For Scenario III, the geothermal system is not competitive due to the heavy burden of the sunk cost amounting to P39.5 M or 48% of the total annual costs.

$$S_G\text{ (III)} = \text{P65.892 M} - \text{P82.782 M} = -\text{P16.8 M per year}$$

For the first two cases, the IRR and PBP are calculated. Tables 7 and 8 present the life-cycle expenditures for a 21-year projection for the geothermal direct-use project. For Scenario I, PBP is between 3 to 4 years and IRR is equal to 23%; for Scenario II, the PBP is between 2 to 3 years and IRR is equal to 40.66%. Compared with PNOC - EDC IRR of 14% and PBP of up to 4 years, these figures indicate that investing on the geothermal energy system is attractive relative to any other projects. Based also on Table 7 and 8, the present worth of the 21-year savings at a 12% discount rate indicate

Table 7: 21 Year Projection for the Geothermal Dirct-Use Project (Scenario I)

| 1 YEAR | 2 ANNUAL FUEL COSTS (CONVENTIONAL) | 3 TOTAL ANNUAL O & M COSTS (GEOTHERMAL) | 4 ANNUAL SAVINGS | 5 PRESENT ANNUAL OF SAVINGS (@12%) | 6 VALUE PRESENT OF CONV. FUEL COSTS (@12%) | 7 PRESENT VALUE OF GEOTHERMAL COST (@12%) |
|---|---|---|---|---|---|---|
| | 36,567,000 | 26,964,000 | 9,603,000 | | | |
| | | | | (59,718,000) | | |
| 1 1990 | 41,028,174 | 29,121,120 | 11,907,054 | 10,631,298 | 36,632,298 | 26,001,000 |
| 2 1991 | 46,033,611 | 31,450,810 | 14,582,802 | 11,625,320 | 36,697,713 | 25,072,393 |
| 3 1992 | 51,649,712 | 33,966,874 | 17,682,837 | 12,586,294 | 36,763,245 | 24,176,950 |
| 4 1993 | 57,950,977 | 36,684,224 | 21,266,752 | 13,515,406 | 36,828,893 | 23,313,488 |
| 5 1994 | 65,020,996 | 39,618,962 | 25,402,034 | 14,413,796 | 36,894,659 | 22,480,863 |
| 6 1995 | 72,953,557 | 42,788,479 | 30,165,078 | 15,282,567 | 36,960,543 | 21,667,975 |
| 7 1996 | 81,853,891 | 46,211,558 | 35,642,334 | 16,122,782 | 37,026,543 | 20,903,762 |
| 8 1997 | 91,840,066 | 49,908,482 | 41,931,584 | 16,935,463 | 37,092,662 | 20,157,199 |
| 9 1998 | 103,044,554 | 53,901,161 | 49,143,393 | 17,721,600 | 37,158,899 | 19,437,299 |
| 10 1999 | 115,615,990 | 58,213,254 | 57,402,736 | 18,482,143 | 37,225,254 | 18,743,110 |
| 11 2000 | 127,177,589 | 62,870,314 | 64,307,275 | 18,486,805 | 36,560,518 | 18,073,713 |
| 12 2001 | 139,895,347 | 67,899,939 | 71,995,408 | 18,479,428 | 35,907,651 | 17,428,223 |
| 13 2002 | 153,884,882 | 73,331,934 | 80,552,948 | 18,460,657 | 35,266,443 | 16,805,787 |
| 14 2003 | 169,273,370 | 79,198,489 | 90,074,882 | 18,431,105 | 34,636,685 | 16,205,580 |
| 15 2004 | 186,200,707 | 85,534,368 | 100,666,339 | 18,391,364 | 34,018,173 | 15,626,809 |
| 16 2005 | 204,820,778 | 92,377,117 | 112,443,661 | 18,341,997 | 33,410,706 | 15,068,709 |
| 17 2006 | 225,302,856 | 99,767,287 | 125,535,569 | 18,283,545 | 32,814,086 | 14,530,541 |
| 18 2007 | 247,833,142 | 107,748,670 | 140,084,472 | 18,216,527 | 32,228,120 | 14,011,593 |
| 19 2008 | 272,616,456 | 116,368,563 | 156,247,892 | 18,141,439 | 31,652,618 | 13,511,179 |
| 20 2009 | 299,878,101 | 125,678,048 | 174,200,053 | 18,058,756 | 31,087,393 | 13,028,637 |
| 21 2010 | 329,865,912 | 135,732,292 | 194,133,619 | 17,968,932 | 30,532,261 | 12,563,328 |
| | | | TOTAL : | 348,577,227 | 737,395,364 | 388,818,137 |
| | | | PBP | = 3 - 4 YRS IRR = 22.99% | | |

Assumptions:

1. All moeny values are in Philippines Pesos.
2. Annual cost for conventional fuel is inflated at 12.2% from 1990 to 1999 and at 11% therafter; all others at 8%.
3. IRR value is computed based on P59.718 million capital cost of the geothermal project.
4. Total annual O & M costs for the geothermal option (column 3) do not include capital recovery and sunk costs.
5. All prices are constant at 1988 values.

Column Operations:
(4) = (2) - (3)

Table 8. 21 Year Projection for the Geothermal Direct-Use Project (Scenario II)

| 1 YEAR | 2 TOTAL ANNUAL O & M COSTS (CONVENTIONAL) | 3 TOTAL ANNUAL O & M COSTS (GEOTHERMAL) | 4 ANNUAL SAVINGS | 5 PRESENT VALUE OF SAVING (@ 12%) | 6 PRESENT VALUE OF CONV. FUEL COST (@ 12%) | 7 PRESENT VALUE OF GEOTHERMAL COSTS (@ 12%) |
|---|---|---|---|---|---|---|
| | 65;892,086 | 43,327,000 | 22,565,086 | | | |
| | | | | (59,718,00) | | |
| 1 1990 | 71,163,453 | 46,793,160 | 25,906,1007 | 23,130,453 | 64,910,060 | 41,779,607 |
| 2 1991 | 76,856,529 | 50,536,613 | 29,701,779 | 23,678,076 | 63,956,554 | 40,278,478 |
| 3 1992 | 83,005,051 | 54,579,542 | 34,011,333 | 24,208,595 | 63,057,235 | 38,848,640 |
| 4 1993 | 89,645,456 | 58,945,905 | 38,901,527 | 24,722,624 | 62,183,812 | 37,461,188 |
| 5 1994 | 96,817,092 | 63,661,578 | 44,447,590 | 25,220,756 | 61,344,045 | 36,123,289 |
| 6 1995 | 10,456,2459 | 68,754,504 | 50,734,279 | 25,703,565 | 60,536,736 | 34,833,171 |
| 7 1996 | 11,297,456 | 74,254,864 | 57,857,071 | 26,171,601 | 59,760,730 | 33,589,130 |
| 8 1997 | 121,961,653 | 80,195,253 | 65,923,500 | 26,625,396 | 59,014,914 | 32,389,518 |
| 9 1998 | 131,718,585 | 86,610,873 | 75,054,663 | 27,065,464 | 58,298,213 | 31,232,749 |
| 10 2099 | 142,256,072 | 93,539,743 | 85,386,907 | 27,492,299 | 57,609,593 | 30,117,294 |
| 11 2000 | 153,636,557 | 101,022,923 | 94,530,180 | 27,175,168 | 56,216,844 | 29,041,676 |
| 12 2001 | 165,927,482 | 109,104,757 | 104,636,146 | 26,875,493 | 54,861,966 | 28,004,474 |
| 13 2002 | 179,201,680 | 117,833,137 | 115,804,945 | 26,539,504 | 53,543,818 | 27,004,314 |
| 14 2003 | 193,537,815 | 127,259,788 | 128,147,038 | 26,221,423 | 52,261,297 | 26,039,874 |
| 15 2004 | 209,020,840 | 137,440,571 | 141,784,268 | 25,903,456 | 51,013,334 | 25,109,879 |
| 16 2005 | 225,742,507 | 148,435,817 | 156,851,024 | 25,585,800 | 49,798,897 | 24,213,097 |
| 17 2006 | 243,801,908 | 160,310,682 | 173,495,521 | 25,268,641 | 48,616,985 | 23,348,344 |
| 18 2007 | 236,306,060 | 173,135,537 | 191,881,220 | 24,952,155 | 47,466,629 | 22,514,474 |
| 19 2008 | 284,370,545 | 186,986,380 | 212,188,381 | 24,636,509 | 46,346,895 | 21,710,386 |
| 20 2009 | 307,120,189 | 201,945,290 | 234,615,780 | 24,321,859 | 45,256,874 | 20,935,015 |
| 21 2010 | 330,689,804 | 218,100,913 | 259,382,605 | 24,008,353 | 44,195,689 | 20,187,336 |
| | | | TOTAL : | 535,489,189 | 1,160,260,121 | 624,770,932 |
| | | | PBO | = 2-3 YRS | IRR = 40.66% | |

Assumptions:

1. All money values are in Philippine Pesos.
2. Annual cost for conventional fuel is inflated at 12.2% from 1990 to 1999 and at 11% thereafter; all others at 8%.
3. IRR value is computed based on P59.718 million capital cost for the geothermal project.
4. Total annual O & M costs for the geothermal option (column 3) include capital recovery and electricity costs but excludes PGI sunk costs.
5. All prices are constant at 1988 values.

Column Operation:
(4) = (2) - (3)

that the investor could afford to spend today P348.58 M (Scenario I) or P535.49 M (Scenario II) to avoid the projected cost of P737.49 M (Scenario I) or P1.16 B (Scenario II) for the conventional energy over the next 21 years.

**Sensitivity Analysis of Costs:**

A sensitivity analysis for various cost fluctuations was carried out and is presented in Table 9. If total conventional energy cost is kept constant, the total geothermal system annual cost can tolerate an escalation of up to 40% (P60.659 M) or if total geothermal energy annual cost is kept constant, the total conventional energy system annual cost can be reduced by the much as -25% (P49.419 M). In both instances, the project would still be above the set minimum IRR of 14% (see Figs. 10 & 11).

By looking at the degree of sensitivity of the annual savings and IRR to each independent change of ± 20% in the cost factors, the ranking of the individual cost factors (see Table 10) are as follows:

1st. Fuel Oil and Electricity Costs (conventional)
2nd. Capital Recovery Cost (conventional)
3rd. Repair and Maintenance Cost (geothermal)
4th. Capital Recovery Cost (geothermal)
5th. Repair and Maintenance Costs (conventional)
6th. Running Cost, i.e. Electricity (geothermal)

The price of fuel oil will greatly affect the viability of the whole project and thus, must be given more thorough evaluation. Based on the original fuel-oil price of P1.9809 per liter, the sensitivity analysis indicate that a price reduction of 45% (or 55% of the original price) or P1.089 per liter can be considered as the bottom line for the project to be still viable. The study also shows that the total change in conventional energy costs (± P13.2 M in annual savings and ± 20% in IRR) is greater than the total change in geothermal energy costs (±P8.7M in annual savings and ± 12% in IRR). This implies that the whole project is more sensitive to changes in the total conventional energy costs.

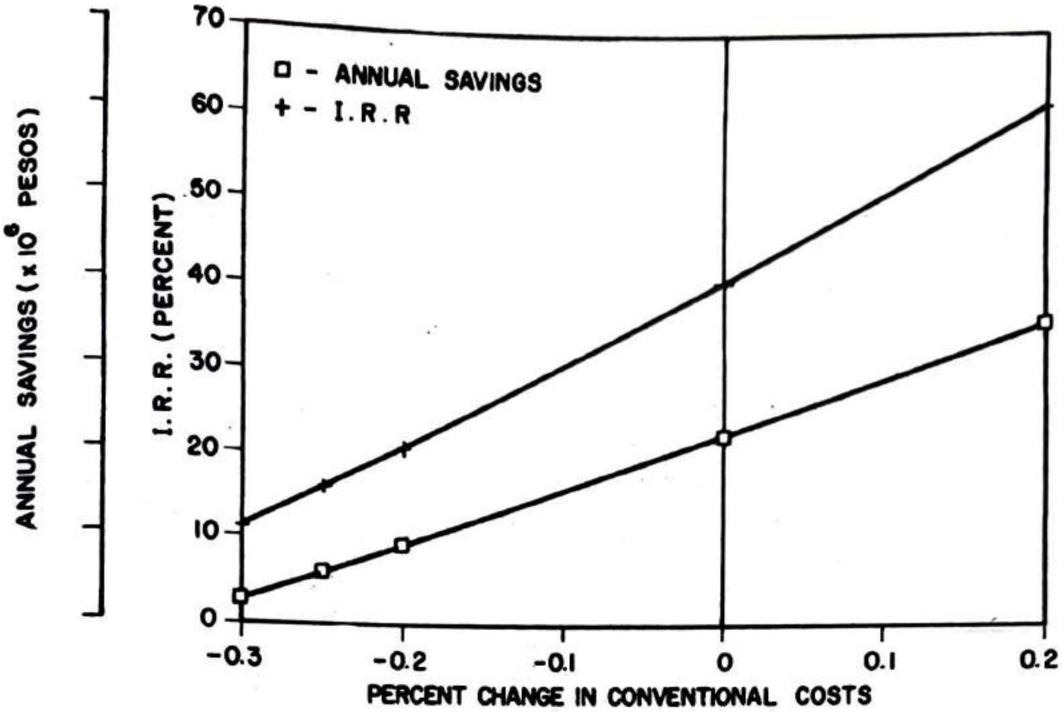


**Figure 10.** Sensitivity of Conventional Energy Costs

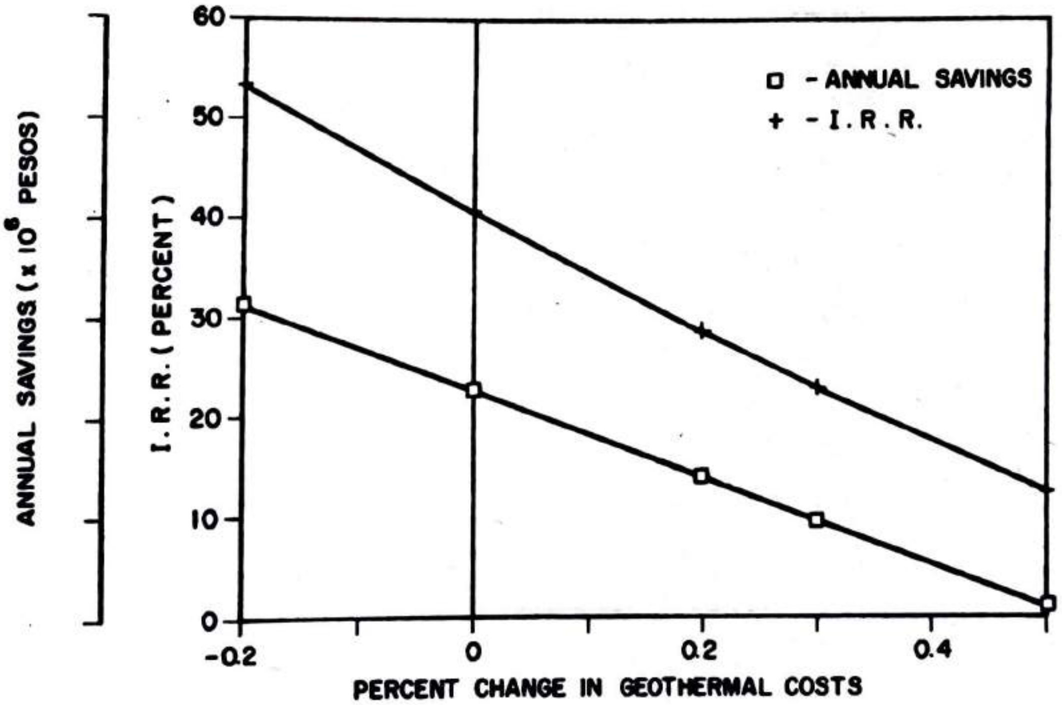


**Figure 11.** Sensitivity of Geothermal Energy Costs

**Table 9**. Sensitivity Analysis of Project Costs (Scenario II)

| | ITEM | ANNUAL SAVINGS (million pesos) | ! R R (5) |
|---|---|---|---|
| I. | GEOTHERMAL O & M (million pesos) | | |
| | BASE CASE (43.327) | 22.565 | 40.66 |
| | +20% (51.992) | 13.9 | 28.6 |
| | -20% (34.662) | 31.231 | 53.42 |
| | +25% (54.159) | 11.733 | 25.74 |
| | +30% (56.325) | 9.567 | 22.94 |
| | +40% (60.659) | 5.234 | 17.57 |
| | +50% (64.991) | 0.902 | 12.48 |
| II. | CONVENTIONAL O & M (million pesos) | | |
| | BASE CASE (65.892) | 22.565 | 40.66 |
| | +20% (79.071) | 35.744 | 61.38 |
| | -20% (52.714) | 9.387 | 20.86 |
| | -25% (49.419) | 6.092 | 16.07 |
| | -30% (42.124) | 2.797 | 11.29 |

**Table 10.** Sensitivity Analysis of Project (Scenario II)

| PARAMETER 1 | CHANGE IN PARAMETER 2 AFTER CHANGING PARAMETER 1 BY: | | | |
|---|---|---|---|---|
| | +20% | | -20% | |
| | ANNUAL SAVINGS (million pesos) | I R R (%) | ANNUAL SAVINGS (million pesos) | I R R (%) |
| I. GEOTHERMAL COSTS: (million pesos) | | | | |
| REPAIR & MAINT. (25.693) | -5.139 | -7.25 | +5.139 | +7.50 |
| RUNNING COST (ELECT.) (1.271) | -0.254 | -0.36 | +0.254 | +0.37 |
| CAPITAL RECOVERY (16.363) | -3.273 | -4.65 | +3.273 | +4.76 |
| TOTAL : | -8.665 | -12.06 | +8.665 | +12.76 |
| II. CONVENTIONAL COSTS: (million pesos) | | | | |
| REPAIR & MAINT. (2.778) | +0.556 | +0.81 | -0.556 | -0.79 |
| FUEL OIL & ELECTRICITY (36.567) | +7.313 | +11.96 | -7.313 | 11.87 |
| CAPITAL RECOVERY (26.547) | +5.309 | +7.76 | -5.309 | -7.49 |
| TOTAL: | +13.178 | +20.72 | -13.178 | -19.80 |

NOTES:

Changes in parameter 2. e.g., annual savings and IRR are based on base case of P22.656 M and 40.66%, respectively as shown in Table 9.

## Conclusion

The process energy requirements of the industrial plant chosen for this study can be supplied by Maibarara Well No. 6. Using geothermal energy for process heating instead of steam from conventional boilers using fuel-oil can result into substantial savings and generate very favorable rates of return over the economic life of the project. A pilot plant study is recommended.

## References

ACHARYA, Hermendra K. & BRIEDIS, John, (1985) Geothermal Energy Sources, ***Handbook of Energy Systems Engineering (Production & Utilization)***, John Wiley & Sons, Inc., U.S.A.

ARMSTEAD, H. Christopher H., (1983), ***Geothermal Energy***, E. & F.N. SPON, New York.

BARBIER, Enrico, (1986), Technical-Economic Aspect of the Utilization of Geothermal Waters, *Geothermics*, Vol. 15, NO. 5/6, pp. 857-879.

BAKEWELL, Charles A. & HERRON, Hunter E., (1979), Low Temperature, Direct-Use Energy Costs, *Geothermal Resources Council, TRANSACTIONS*, Vol. 3, pp. 23-26.

DATUIN, Rogelio & TRONCALES, Alfredo, (1986), Philippine Geothermal Resources: General Geologic Setting & Development, *Geothermics*, Vol. 15, No. 5/6, pp. 613-622.

DREW, Stephen, (1987), Direct Use Projects Equipment and Controls (A reference material used during the 1st Workshop on Small Geothermal Resources, Pisa, 11-12 May 1987).

DREW, Stephen & SIITONEN, Harri, (1988), Heat Exchanger Papers (A reference material used during the ODA, ECP, Philippines Non-Electrical Applications Training Course, Rotorua, New Zealand, 29 Feb. 1988 - 18 March 1988).

EASTLAKE, William B., (1980), A Primer on Economic Feasibility for Direct-Users, *Geothermal Resources Council, TRANSACTIONS*, Vol. 4, pp. 703-705.

GOODMAN, Louis & LOVE, Ralph, (1980), *Geothermal Energy Projects - Planning & Management*, Published in cooperation with the East-West Center, Hawaii.

HOLMAN, J.P., (1983), *Thermodynamics*, McGraw-Hill Book Company, Tokyo, Japan.

LUND, John & ANDERSON, David, (1979), *Direct Utilization of Geothermal Energy: A Technical Handbook*, Geothermal Resources Council Special Report No.7, Davis, CA, pp. 4-5 to 4-9, 4-25 to 4-41.

MEYER, Richard T., (1980), Target Industries for Geothermal Direct Heat Applications, *Geothermal Resources Council TRANSACTIONS*, Vol. 4, pp. 589-592.

MIKIC, Borivojė & MEAL, Harlan C. & GUILAMON-DUCH, Higinio & PACKER, Michael B., (1980), Thermal Design Optimization of Industrial Processes When Geothermal Energy is Available, *Geothermal Resources Council, TRANSACTIONS*, Vol. 4, pp. 593.

NIESS, Richard, (1980), High Temperature Heat Pumps can Accelerate the Use of Geothermal Energy, Commercial Uses of Geothermal Energy, Geothermal Resources Council Special Report No. 9, pp. 88-90.

OELERT, Gerhard & FINCK, Horst, (1985), *A Guide to the Financial Evaluation of Investment Projects in Energy Supply*, Duetsche Gesslischaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn.

REAY, David A., (1977), *Industrial Energy Conservation*, Pergamon Press, Oxford, Great Britain.

ROXAS, Fernando Yan, (1987), Prospects for the Development of the Maibarara Geothermal Area, *Thesis, Asian Institute of Management*, Manila, Philippines.

SINGH, Paul R., (1986), Energy Accounting of Food Processing Operations, *Energy in Food Processing*, Vol. 1, pp. 19-23, 57.

SINCIOCO, Jaime S. & PAGUILIGAN, Emma C., of Philippine Institute of Volcanology and Seismology, Non-Electrical Applications of Geothermal Steam in the Philippines ( A paper delivered during the PCIERD Symposium on Energy Technologies, April 25-26, 1988, Manila, Philippines).

TESTER, Jefferson, (1982), Chapter 10: Energy Conversion and Economic Issues for Geothermal Energy, ***Handbook of Geothermal Energy***, Gulf Publishing Company, Houston, Texas.

TOLENTINO, B.S. & ALCARAZ, A.P., (1982), The Phenominal Growth of Geothermal Development in the Philippines, (A paper delivered during the convention of Philippine Society of Mechanical Engineers - PSME).

WEHLAGE, Edward F., (1975), ***The Basics of Applied Geothermal Engineering***, Geothermal Information Services, West Covina, California.

WRIGHT, Philip M., (1980), Nature and Occurrence of Geothermal Resources, Commercial Uses of Geothermal Heat, ***Geothermal Resources Council Special Report No. 9***, P.O. Box 98, Davis, CA 95616, pp. 123-124.

1982 World Bank Energy Sector Report, pp. 101-102.

1988 World Bank Energy Sector Report, pp. 29-39, 106-111.

Geothermal Energy, 1982 Applications Handbook, ASHRAE Handbook, Atlanta, U.S.A.

Project PHI/85/003, Development of Geothermal Energy for Power and Non-Electrical Uses for Los Baños (Mak-Ban) Geothermal Project, July 1988, Manila, Philippines (A project by PNOC - Energy Development Corporation and the United Nations Development Programs).

Project PHI/85/003, Development of Geothermal Energy for Power and Non-Electrical Uses for the Palimpinon Geothermal Project, July 1988, Manila, Philippines (An Agro-Industrial Development Plan prepared by PNOC - EDC and UNDP).

Environmental Characterization Report (December, 1982), Bulalo Geothermal Project, Los Baños, Laguna, Philippines (A study sponsored by NPC and PGI).