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NAQU MULTI-PURPOSE GEOTHERMAL PROJECT

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ABSTRACT

Geothermal exploration and application in Tibet dates back to year of 1972. It has been developed rapidly in recent years. Since the first 1 MW geothermal turbine generator was taken into use in 1976 in the Yang Ba Jing Geothermal Power Plant. So far 2 geothermal power plants have been commissioned with a total capacity of 14 MW from 6 geothermal turbine units. The geothermal for the electric power generating purpose has a temperature range from 105 - 135°C in Tibet.

The Naqu Multi-Purpose Geothermal Project would be the third geothermal utilization project in the northern part of Tibet where a solution to the energy and fuel shortage problem is urgently needed. This project consists of 5 subprojects: a 2 MW geothermal power plant; a district heating system with heating floor area of 20,000 m^2; 5,000 m^2 greenhouse; hot tap water; public bath and woolwashing. The design borehole temperature is 112°C with a total flow rate of 282 kg/s. It is estimated that 5,357 kW thermal energy is needed with a flow rate of 41 kg/s for district heating system, hot tap water and public bath. The supply hot water temperature is 70°C and 40°C return. It is expected that about 1.18 million RMB yuan can be gained from selling the electricity per year. The annual net earning of the project is about 3.4 million RMB yuan.

It is emphasized in the report that available data about the geothermal area and geothermal fluid are limited. For this reason the analyses presented are based on many assumptions which may or may not be true. When better data become available all the results will have to be reviewed and reworked.

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1. INTRODUCTION

Geothermal energy is being utilized in many countries of the world and the potential use of geothermal fluid world-wide is considerable. Table 1.1 (Ref.1) shows the estimated direct use world-wide of geothermal energy including fish farming, swimming pools and balneology, space heating of buildings and greenhouses, drying and evaporation. There are many examples and experiences of these and other direct and indirect uses of geothermal energy world-wide. They range in application temperature from about 20°C to almost 200°C (Fig. 1.1, Ref. 1).

This report describes a geothermal multi-purpose project designed for the economic development of Naqu town in Tibet P.R.C. The author has been studying geothermal energy utilization at UNU Geothermal Training Programme in Iceland for six months since April 27, 1987. As a result of his studies, the author attempts with this final report to find a way in which the problems of energy shortage may be solved using geothermal energy. This multi-purpose project consists of several subprojects including a 2 MW geothermal power plant, district heating system heating a total area of 20,000 m^2, public bath, hot tap water usage, greenhouse heating and woolwashing. In this report, the project principles, design considerations, power cycle, heat demand, and system design will be discussed. Since Naqu geothermal field has a low temperature and pressure reservoirs, the thermodynamic efficiency and economic feasibility will also be discussed in the report.

It is to be emphasized at this time that the data about Naqu geothermal field properties are very limited. For this reason, many assumptions about these properties have been made in this report which may or may not be true. For this reason all conclusions and results obtained have to be viewed with this in mind. When the complete data about the field become available, all the analyses reported herein will have to reworked and reviewed. The same uncertainties apply to building data and data about usage (for example tap water). Problems of environmental pollution are often encountered in geothermal development. Such problems are not considered or discussed in the report.

2. PRELIMINARY PARAMETER

2.1. General

Naqu town is the capital of Naqu district in the north part of Tibet with latitude 32 degrees north and longitude 92 degrees east. The population in Naqu town is about 12,400. It is about 360 km north from Lhasa the capital city of Tibet and 740 km south from Geremu railway station in Geremu city. The Qin-Zang highway from Lhasa to Geremu runs though Naqu town. The elevation there is 4,400 meters above sea level. A diesel generator power plant with an installed capacity of 1,680 kW is presently used to supply electricity to Naqu town. The annual electricity production is 1,200 MWh. The production cost is 0.75 RMB yuan (0.2 US dollars) per kWh (The hydropower production cost is 0.06, the geothermal power production cost is 0.10 and the production cost at Lhasa power plant is 0.35 RMB yuan per kWh). Because of the high production cost, the daily generating period is only 4 hours(from 20 to 24) for lighting. The house heating and cooking fuel mainly used is dry yak dung with a total consumption of about 20,000 tonnes (1,000-1,500 kcal/kg) per year. The electricity for industrial and commercial activities is supplied by their own diesel generator units with a total capacity of 2,400 kW. The production cost is even higher than that of the municipal power plant.

Since Naqu district is a large grasslands area and the main animal husbandry base in Tibet, Naqu town is the political and economic center in north part. Continued development of the resources in the area is therefore needed.

2.2. Meteorological Data

Naqu town is located at a high elevation. The annual mean temperature is -2°C. Annual mean minimum temperature is estimated as -28°C and the lowest temperature is about -35°C in February. Estimating temperature by using dry adiabatic lapse rates Lhasa would have a mean minimum temperature of -20°C and Khashgar would be -40°C if they were at the same elevation as Naqu town (table 2.1 , Fig.2.1, Ref.2). The annual mean atmospheric pressure is 0.6 bar. The average annual rainfall is 407 mm. The mean wind velocity is 2.9 m/s. The annual sunshine duration is about 3,000 hours with the solar energy of 180 W/m^2. The annual sunshine ratio is about 65 %. (Ref.3)

2.3. Hydrological Data

There is a river called the Naqu River which runs through Naqu town and passes by the geothermal field. Its minimum flowrate is about 0.2 m^3 per second in the winter.

Another river called the Ciqu River runs in a direction from west to east at a distance of approximately 5 km from the geothermal field (see next section). The flow rate of this river is considerably larger than that of the Naqu River.

2.4. Geothermal Field

The Naqu geothermal field is located 2 km to the south-east from Naqu town. The total area of the field is about 3 - 4 km^2. Before exploration of the field started, a bath pool was built by the local people using the hot spring water. In 1984, the Scientific and Technological Commission of Tibet funded an investigation of the Naqu geothermal field. This investigation was carried out by the Qin-Zang Plateau Exploration Team of the Academy of Sciences of China for the purpose of finding a way to solve the problem of energy shortage in the area. In the same year, the Bureau of Geology and Minerals of Tibet sent a team to the field for exploration. Since 1984 12 exploration wells have been drilled, 5 of which are mainly for temperature measurements. At the same time some geochemical and geophysical surveys have been carried out such as resistivity surveying, surface geological mapping in the scale of 1:10,000, and gravity and magnetic surveying. The preliminary exploration results show that the Naqu geothermal field consists of two anomaly areas, the east area and the west area. The east area within 15 ohmm line is about 2.5 km^2. There are 3 aquifers, at depths of 75 - 110, 290 - 315, and 470 - 500 meters from surface. The geochemistry surveys have shown that the main chemical components of hydrothermal fluids sampled at surface manifestations were HCO_3-Na, HCO_3-Ca, HCO_3-Mg-Ca, HCO_3-SO_4- Ca, pH about 7 - 8, and salinity of 2.7 - 3.2 g/l. The temperature found in the wells reached a maximum of 112°C measured at the well head and a pressure of 1 - 2 bar (Ref.4). Two of the 12 wells have been used for the space heating system of Naqu hotel and hospital. Table 2.2 shows the data for the two wells, and Table 2.3 shows the parameters of the geothermal field. The west area is under exploration. The final reports for the above described investigations of the Naqu geothermal field are expected to be finished in June 1988.

2.5. Existing District Heating System

The existing district heating system for the Naqu Hotel and Naqu Hospital was taken into use in 1985. The system is a single pipe system using the geothermal water directly from a separator near the wellhead (Fig. 2.2). It was designed to heat the Naqu hotel and hospital with a total floor area of 20,000 m^2. The supply water flowrate is about 30 kg/s at a temperature of about 100°C. The return water temperature is about 60°C. The existing system pipeline from the well site to heating area is about 2,500 m long with a diameter of 325 mm and it is insulated with a 60 mm thick blanket of glass wool. The main problems of the system are scaling and corrosion. Another problem is lack of control of the indoor temperature which at times become too high (about 30°C).

3. PROJECT PLANS AND DESIGN CONSIDERATIONS

3.1. General

The geothermal multi-purpose project discussed in this report is the first test project to be studied in Tibet. The author attempts to show that the living and social development condition can be improved by using geothermal energy. The project is based on the following main principles:

1. The project may be divided into two main parts, electric power generation and a direct heat utilization. If the final reservoir report indicates that the field is not exploitable for electric power generation, the direct heat utilization scheme can still be carried out.

2. As discussed in the introduction, there are many uncertain factors and parameters which are assumed. This report will therefore need to be revised when the complete field data become available.

3. The economic analysis is based on local condition in Tibet and are difficult to compare with other countries or regions.

3.2. Load

According to forecasts the electrical power requirement of the Naqu district will be 6 MW in 10 years. As the first step of the geothermal exploitation scheme, two 1 MW turbine generator units are planned to be installed. If the final exploration report for the geothermal field indicates a possibility of more electric power generation, the installed capacity can be increased as a second phase. The 2 WM electric power will supply the base load and the present diesel power plant can be used for peak load purpose and as a stand-by unit.

3.3. Power Cycle

The power cycle of the power plant is designed as a single flash cycle. In wet fields it is possible to extract substantial amount of supplementary power from the hot borehole fluid by passing it through a separator. The unflashed fraction of the hot water is rejected to waste or it may be put to some other use. We have the experience of operating the single flash system in the Ali geothermal power plant in Tibet, where the power generation units are the same as those planned for the Naqu power plant (Fig.3.1). It can be mentioned here that it may be possible to use a single flash-binary cycle using the unflashed hot water at a temperature of 85-90°C (Fig. 3.2). Thus more electric power may be generated without new wells. This system will be discussed briefly in section 4.5.3.

3.4. Resource Capacity

As mentioned in section 2, the final exploration report of the Naqu geothermal field will be finished by June 1988 year. Results of the exploration work already done seem to indicate that it may be possible to supply the thermal energy for 2 MW generating units. It is therefore assumed here that the resource capacity is sufficient for the project design purposes.

3.5. Borehole Fluid Properties

The properties of the borehole fluid may cause problems because of calcite deposition in the production wells and surface equipment such as separators, pipelines and heat exchangers. A clean-out device has been developed for the removal of calcite scaling in boreholes in the Yang Ba Jing geothermal power plant in Tibet, which is lowered down the wellbore on a steel cable. The hollow sleeve which is lowered down the well is about 80 kg in weight.It scrapes the deposits, and the debris is subsequently carried by the well flow out of the well (Fig. 3.3, Ref.4). This method has enabled the plant to keep the wells in production in spite of the heavy scaling. The same method could be used in Naqu power plant to clean the calcite scaling from the production wells. Other methods to clean the separator and the pipeline can also follow Yang Ba Jing experience.

The chemical compositions and temperature of geothermal fluids vary widely from site to site. It is therefore extremely difficult to estimate potential scaling problems unless fields tests are performed. Such tests will have to be made in order to determine which type of heat exchangers are suitable. One type which has been widely used in geothermal installations, for example in France and in Iceland, is the plate heat exchanger using plates made of stainless steel or titanium. Another type which shows promise for geothermal applications is the fluidized bed heat exchanger. This type, however, is a recent development which has been in use only for a few years. When and if the project is to be carried out, the problem of scaling might be solved by choosing one of these two alternative. It is to be emphasized that the plate heat exchanger employs expensive material resistant to corrosion and needs regula cleaning by disassembly. The fluidized bed heat exchanger built of common commercial grade material and self cleaning. It needs regula supply of FB material.

3.6. Thermodynamic Efficiency for Electricity Production

The thermodynamic efficiency is related to wellbore temperature as is well known in the geothermal utilization field. The second law of thermodynamic imposes stringent limitations on the production of electricity from a low-temperature geothermal heat source. Inasmuch as one extracts useful work, a specialized ideal process must be assumed. In one scheme, an infinite number of infinitesimally small reversible Carnot heat engines would be required. The maximum amount of work would then result from taking the geothermal fluid at wellhead conditions (temperature T_{gf} and pressure P_{gf}) and allowing heat to be removed through these Carnot engines to produce work and reject an amount of heat to the environment at temperature T_0. This process would continue until the geofluid reached the so-called dead state or ambient condition (T_0, P_0). The maximum work which can be extracted is expressed by a quantity called the availability ΔB, as follows:

$$W_{max} = \Delta B = (h_{gf} - h_0) - T_0 * (s_{gf} - s_0) \ , \qquad (3.1)$$

where h_{gf}, h_0 = enthalpy at the state T_{gf}, T_0 kJ/kg

s_{gf}, s_o = entropy at the state T_{gf}, T_0 kJ/kgK

The availability is plotted in Fig. 3.4 for saturated steam and water over a range of T_0 from 25 to 45°C. This maximum work quantity can then be compared to the actual amount of work produced by any real power conversion process (W_{net}). Comparisons of this type are usually achieved by defining a cycle efficiency ($\hat{U}_{cycle}$), which represents the net useful work, W_{net}, obtained from the system divided by the amount of heat transferred from the geothermal fluid, Q_h. As the cycle efficiency decreases, the amount of heat rejected to the environment increases. For an ultimate sink of 25°C, with a geothermal heat source of 50°C, cycle efficiency would be less than 5 %. As the temperature increases to 100°C, the efficiency would be about 8 %; at 150°C, 12.5 %; and at 200°C, 17.5 %. A typical range of cycle efficiency is shown in Fig. 3.5 as a function of geothermal fluid and condensing temperature (Ref. 5).

According to this theory and equation 3.1, the thermodynamic efficiency can be defined as follows:

$$W_{max} = (h_{gf} - h_0) - T_0*(s_{gf} - s_0) \ , \qquad (3.2)$$
$$= 335.6 \text{ kJ/kg}$$

where T_{gf} = 90 °C
T_0 = 44 °C
T_w = 112 °C (wellhead temperature)
h_{gf} = 2,660.1 kJ/kg: enthalpy of steam from separator
h_0 = 184.17 kJ/kg: enthalpy of water at 44°C
s_{gf} = 7.4799 kJ/kgK: entropy of steam from separator
s_0 = 0.6252 kJ/kgK: entropy of water at 44°C

The steam fraction of the borehole fluid is:

$$X = (h_w - h_0)/(h_{gf} - h_0) \ , \qquad (3.3)$$
$$= 0.04$$

where h_w = 469.78 kJ/kg: enthalpy of borehole fluid
which gives:

$$W_{net} = W_{max} * X$$
$$= 335.6 * 0.04$$
$$= 13.4 \text{ kJ/kg}$$

The total flowrate from wells ZK 1303 and 1005 is 80 kg/s. Then, the electric power production of the two wells is given:

$$P_e = W_{net} * Q \quad MW_e \ , \qquad (3.4)$$
$$= 1.1 \ MW_e$$

where Q = total flowrate, kg/s

For each well the power is about 0.6 MW_e.

The thermal energy from fluid is:

$$P_t = h_w * Q , \tag{3.5}$$
$$= 18.8 \quad MW_t$$

The thermodynamic efficiency is then:

$$\eta = P_e/P_t = 3.2 \% \quad , \tag{3.6}$$

The average worldwide geothermal power generation per well is about 10.2 MW_e/well (max. 18.5 MW_e/well, min. 3.6 MW_e/well). The thermodynamic efficiency is 10% - 20%, with an average efficiency of 15% (Fig. 3.6, Ref.6). Comparison of the Naqu geothermal wells with the world average shows that the thermodynamic efficiency is very low because of the low temperature. This means that more wells are needed for electricity production. This aspect will be discussed in section 5.

4. PROJECT DESIGN

4.1. General

The general arrangement of the multi-purpose development discussed in this report is shown in a simplified line diagram in Fig. 4.2. Following the path of the geothermal field from the reservoir it goes through the following steps:
1. From the borehole the fluid flow is piped into a separator. In the reservoir it is in the liquid phase (water dominated system) at a temperature of 112°C, and the flow up through the borehole into the separator is assumed to take place under isenthalpic conditions.

2. As the fluid enters the separator its pressure is dropped to 0.7 bar abs. causing flash boiling. The fluid is partly evaporated and the two phases, the vapor phase or steam phase and the liquid phase or water, both at a temperature of 90°C, are separated and leave the separator through separate outlets.

3. From isenthalpic conditions it is found that the borehole fluid at a temperature of 112°C in the liquid phase will separate into 4.0 % steam and 96.0 % water (by weight) when flashed at 0.7 bar abs. These are then the mass flow ratios between separated steam and water leaving the separator.

4.2. Heat Demand of District Heating System

4.2.1. Design Parameters

This heating system is designed using hot water at a temperature of 70°C for the Naqu Hotel and Hospital.
The estimated heat requirements are based on the local weather conditions, Icelandic experience, the former design of Naqu hospital heating system and some Chinese standards.

According to the former hospital heating system design, which was made by the Chinese Sixth Building Company, Design Department, the temperature is at 18°C indoor and -28°C outside. The heat is supplied by steam from a boiler at a pressure of 1 - 2 kg/cm^2 (Ref. 7). The building size and type is roughly estimated based on the former design drawing. The new scheme assumes that hot water is supplied from a heat exchanger which is heated by water from a separator at a temperature of 90°C. Thus the design parameters are determined as follow:

Indoor Temperature:	18°C
Outside Temperature:	-28°C
Annual Mean Temperature:	-2°C
Supply Hot Water Temperature:	70°C
Return Water Temperature:	40°C
Total Heating Area:	20,000 m^2
Hospital Area:	4,000 m^2
Hotel Area:	16,000 m^2

4.2.2. Existing System

The heat requirements are computed on the basis of Chinese standards shown in tables 4.1 and 4.2. The thermal transfer coefficient k for the wall, roof, and floor of Naqu hospital and hotel are calculated as shown in table 4.3. The wall, roof and floor area and volume of the hotel and hospital are roughly estimated based on the heating system drawing.
The heat loss of hospital is computed as shown in table 4.4 according to the formula:

$$Q = k * A * (t_i - t_0) \qquad (4.1)$$

where Q = heat loss W
k = thermal coefficient $W/(m^2 {}^\circ C)$
t_i = indoor temperature °C
t_0 = outside temperature °C
A = surface area m^2

Then the total heat loss of the hospital is found as 1,068 kW. The heat demand is 54.5 W/m^3. Since the author has no detailed information about it, it is assumed that the same heat demand applies to hotel. Then the heat loss of the hotel is estimated as 2,938 kW as shown in table 4.5. The total heat demand for the district heating system is then Q_d = 4,006 kW (table 4.6). The above results are based on a value of 0.8*house volume air infiltration rate per hour. This is a design value commonly used in Iceland but it may very likely be too low for Tibet.

4.2.3. Hot Tap Water

This subproject is designed to supply the hot tap water for hotel and hospital guests, patients and staff use. It is assumed that the users are 1,000 persons per day. The method used to estimate the hot tap water consumption is by combination American standards and Icelandic experience with the local habits. From this the local consumption standards is estimated.

According to American standards of ASHE & ASHRE, 1957: The Standard for Comfort Air Conditioning, the hot tap water consumption for hotels and apartments, is 0.151 m^3 (40 gallon) per person per day at a temperature of 60°C (140°F). Then the hot water consumption is 148.5 kg per person per day. The thermal energy consumption is 37.3 MJ per person per day (Ref. 8).

The Icelandic experience (Ref. 9) says that the annual hot tap water consumption is 30 metric tons per person at a temperature 80°C. The daily consumption is then 82 kg. Then the thermal energy consumption is given as 27.5 MJ per person per day.

As mentioned above, it is estimated that the hot tap water users are to be as many as 1,000 people daily. The hot tap water temperature is 70°C, the same as of the district heating system. The hot tap water consumption is estimated as

40 metric tons per person per year. The daily thermal energy consumption is 32 MJ per person. The heat demand is $Q_w = 370$ kW.

4.2.4. Public Bath

This project is designed for public service for the benefit and enjoyment of the local residents. The heat demand is estimated based on a assumption of 100 customers per day (20 kg/person). The hot water consumption is then estimated 720 t/year. The heat demand is $Q_b = 20.3$ kW (the working time is 8 hours daily).

4.2.5. Power Plant Own Use

This design is for heating the workshop, office buildings, residences and the supply of the hot tap water for the staff. It is assumed that the total building area is 3,000 m^2. The heat demand is then 918 kW (table 4.7). The staff in the plant is assumed to be 100 persons. The annual hot tap water consumption is 4,000 t/yr according to the standards mentioned before. The heat demand is given then as 42.5 kW. The total heat demand for the power plant own use is $Q_p = 960$ kW.

4.2.6. Total Heat Energy Demand

The heat requirement for the direct use scheme is obtained from the heat demand of the four subprojects. It should be mentioned here that the peak load is probably overestimated because only a few guests stay at the hotel during the winter. In the summer the temperature is much higher than in winter, so the heat demand is reduced. The total heat requirement is given as follow:

$$\begin{aligned} Q_t &= Q_d + Q_w + Q_b + Q_p \\ &= 5{,}357 \text{ kW} \end{aligned} \tag{4.2}$$

4.2.7. Hot Water Requirements

The supply of hot water needed is given by the formula: (Table 4.8)

$$m_h = Q_t/(t_d*4186) \quad kg/s \qquad (4.3)$$
$$= 41 \ kg/s$$

where m_h = flowrate kg/s
Q = heat demand W
t_d = temperature difference °C
$t_d = T_f - T_b$
T_f = inflow water temperature, °C
T_b = return water temperature, °C

The geothermal hot water needed from separator to heat the cold water (supply water) is then given by the formula:

$$m_c \ (T_{c,out} - T_{c,in}) = m_g \ (T_{g,in} - T_{g,out}) \qquad (4.4)$$

where, m_c = mass flow of cold water 45 kg/s
m_g = mass flow of geothermal water
$T_{c,out}$ = outlet temperature of district heating water, 75°C
$T_{c,in}$ = inlet temperature of district heating water, 35 °C
$T_{g,in}$ = inlet temperature of geothermal water, 90 °C
$T_{g,out}$ = outlet temperature of geothermal water, 60 °C

then, m_g = 60 kg/s

4.3. District Heating System Design

In the District Heating part of the multi-purpose project it is planned to improve the existing heating system of the Naqu Hospital and Naqu Hotel. At the present time these two systems are heated by means of separated borehole fluid piped directly through the heating systems and subsequently wasted. This fluid contains considerable amounts of minerals causing problems with scaling and deposits. The proposed improvements consist of the following steps:

1. Tests will have to be made on different types of heat exchangers to determine which type is the best suited for conditions of the Naqu geothermal field. Plates heat exchangers using plate of stainless steel have in many instances proved satisfactory for geothermal applications in Iceland. In France such heat exchangers are also common using plates of titanium due to the high chloride contents of geothermal water. Another type of heat exchangers showing promise for geothermal applications are the so-called fluidized bed heat exchangers. These heat exchangers are a recent development and have recently been tested in geothermal environment in Iceland. At this stage, however, it is too early to tell if they are practical for long term geothermal use.

2. The existing 324 mm (12") pipeline running from the geothermal field to Naqu town will be used as a return line for the closed circuit district heating system. The line diameter is somewhat large for transporting the 45 kg/s peak flow of water which then moves at a velocity of only 0.59 m/s. A new 219 mm (8") supply line will be added, which results in a more appropriate flow velocity of about 1.30 m/s and thereby less cooling of the supply water.

3. In order to circulate the district heating water from the heat exchanger station to Naqu town and back a pumping station is needed. In order to evaluate the size of the

circulating pump the pressure losses in the pipeline, the heating systems and the heat exchanger station must be determined. This is done in the following table based on a peak flow of 45 kg/s:

Part of closed district heating system	Pressure loss, bar
Supply line, ID = 219.1 - 9.0 = 210.1 mm, L = 2,500 m	1.40
Return line, ID = 323.9 - 11.2 = 312.7 mm, L = 2,500 m	0.20
Pressure loss across heating system (est.)	2.0
Pressure loss across heat exchanger (est.)	2.0
Total pressure to be supplied by circulate pump	5.60

The circulating pump is then required to deliver 45 kg/s of water against a head of 57 m. The pumping power needed is about 42 kW assuming a pump efficiency of 60 %.

4.4. Power Plant System Design

The power plant system makes use of the steam at a pressure of 0.7 bar abs. leaving the separator. Following its path it is seen from Fig. 4.2 that it takes the following route:

1. From the separator the steam is piped directly into a turbine. This phase of the project will make use of two existing turbo-generator units, each of 1,000 kW capacity. These units are designed for an inlet pressure of 0.7-1.1 bar abs. and exhausting at a condenser pressure of 0.09 bar abs. The lowest design value of the inlet steam pressure is chosen in order to produce the maximum possible steam flow from the low temperature borehole fluid.

2. It is found that in order to produce 2,000 kW from the saturated inlet steam at 0.7 bar abs. exhausting at 0.09 bar abs. at the turbogenerator efficiency specified for the generating units (71 %), a total steam flow of 10.3 kg/s is needed (Fig. 4.2).

3. The exhaust steam from the turbines goes to a mixing condenser where it is condensed at a pressure of 0.09 bar abs. Assuming cooling water available at a temperature of 5°C, the rate of cooling water flow needed is about 150 kg/s. This means that water flow from the condenser (cooling water + condensate) will be at a rate of about 160 kg/s at a temperature of 40°C, the saturation temperature of water at 0.09 bar abs. It might be necessary to use a cooling pond or a cooling tower in order to obtain cooling water temperature of 5°C.

4. The exhaust steam going to the condenser will undoubtedly contain incondensible gases which must be removed from the condenser, if the low pressure of 0.09 bar abs. is to maintained. The most common method utilized in geothermal power plants for this purpose is to raise the pressure of these gases by use of steam ejector so that they may be exhausted into the atmosphere. The amount of steam needed for this purpose will depend on the amount of incondensible gases present in the steam, which is not known at this time. It will be assumed here that the amount of steam needed for this purpose will be about 10 % of the steam flow to the turbines.

5. The amount of steam used for power generation and gas removal is then 10.3 + 1.0 = 11.3 kg/s. This means that the necessary flow of borehole fluid to the separator station is about 282 kg/s. The rate of flow of separated water leaving the separator at 90°C is then about 271 kg/s. This water will be put to other uses as described below.

4.5. Other Possible Types of Utilization

As seen from the above analyses there is still considerable amount of hot water left over when the needs of the district heating system have been taken care of. Of the 271 kg/s of separated borehole water leaving the separator only 60 kg/s are needed for district heat exchangers. This leaves the following amount of water available:

Separated borehole water at a temperature of 90°C	211 kg/s
Borehole water returning from heat exchanger at 60°C	60 kg/s
Cooling water + condensate leaving condenser at 40°C	160 kg/s

There are several ways one may consider using this water. Amount the possibilities the following are mentioned:

4.5.1. Greenhouse Heating

1. Heating loss for greenhouse heating. Heat loss for a greenhouse is composed of three components: (1) transmission loss though the walls and roof, (2) infiltration and ventilation loss due to the heating of cold outside air, and (3) radiation loss from greenhouse to the sky. The transmission loss can be defined as follow:

$$Q_1 = SA_1 * DTD_1 * HLF_1 + SA_2 * DTD_2 * HLF_2 + FA * DTD_f * HLF_f \tag{4.5}$$

where Q_1 = transmission heat loss, kW
SA = surface area, it is divided into SA_1, the walls surface area and SA_2, the roof surface area, m^2
FA = floor area, m^2
DTD = design temperature difference between inside and outside, °C
DTD_f = design temperature for floor, °C
HLF = heat load factor, $W/(m^2{}^\circ C)$
HLF_f = heat loss factor for floor, $W/(m^2{}^\circ C)$

For glass, HLF = 6.24 $W/(m^2{}^\circ C)$ at a wind speed of 24 km/h. If other wind speeds are expected to occur at the design outside condition, the allowances should be made for this by adjusting the HLF according to the following table (Ref. 10):

HLF Values (W/m^2 °C) at Various Wind Velocity (km/h)

Wind Vel.,km/h	0	8	16	32	40
HLF, W/m^2 °C	4.341	5.397	5.902	6.470	6.583

The infiltration loss is generally analyzed via the " air change" method. This method is based on the number of times per hour that the air in the greenhouse is replaced by cold air leaking in from outside. It can be defined by the formula:

$$Q_2 = (AC/H)*V*DTD*0.102 \qquad (4.6)$$

where: Q^2 = infiltration heat loss, kW

AC/H = Air Change/Hour, for single glass, usually at the order of 2.5 - 3.5 times per hour

V = Volume of greenhouse, m^3

The radiation loss from the greenhouse to the sky is given by (Ref. 11)

$$Q_3 = e*\sigma*FA*(T_1{}^4 - T_2{}^4) \qquad (4.7)$$

where e = emissivity of ground (assumed = 0.9)

σ = Stefan Boltzman constant = $5.73*10^{-8}$ $W/(m^2K^4)$

T_1 = temperature of glass outside surface, 256 K

T_2 = temperature of sky, 173 K (assumed)

The total heat loss Q_t can then be given as:

$$Q_t = Q_1 + Q_2 + Q_3 \text{ kW} \qquad (4.8)$$

2. Heat demand of Naqu greenhouses. For the subproject, the total areas of greenhouses are suggested as 5,000 m^2 that

consists of 5 greenhouses at each area 1,000 m^2 (10 * 100 m). For the calculation process, it is assumed that the wall is 2 m high and the top of the roof is 2 m high. All the materials of the walls and roofs are glass with steel frames. The design outside temperature is -28°C, inside temperature is 22°C. The wind speed is assumed at 16 km/h. Then the heat loss can be calculated by the formulas (4.5), (4.6), (4.7), (4.8).

(1) Transmission loss:

$$Q_1 = SA_1 * DTD_1 * HLF_1 + SA_2 * DTD_2 * HLF_2 + FA * DTD_f * HLF_f$$

$$= 545.6 \text{ kW}$$

$SA_1 = 440\ m^2$

$SA_2 = 1,080\ m^2$

$FA = 1,000\ m^2$

$DTD_1 = DTD_2 = 50\ °C$

$DTD_f = 24°C$

$HLF_1 = HLF_2 = 5.9\ W/(m^2\ °C)$

$HLF_f = 4.05\ W/(m^2 °C)$

(2) Infiltration loss:

$$Q_2 = (AC/H) * V * DTD * 0.102$$

$$= 38.25 \text{ kW}$$

$AC/H = 2.5$

$V = 3,000\ m^3$

$DTD = 50\ °C$

(3) Radiation loss

$$Q_3 = e * \sigma * FA * (T_1{}^4 - T_2{}^4)$$

$$= 175.3 \text{ kW}$$

(4) Total heat loss Q_t:

$$Q_t = Q_1 + Q_2 + Q_3$$

$$= 759.2 \text{ kW}$$

$$= 486.65 \text{ kW}$$

3. Hot water requirement for greenhouses. It is proposed to use the 40°C water coming from the condenser for supplying heat to the greenhouses. The hot water requirements are:

$$Q_g = Q_t/(\Delta T*4.1868)$$
$$= 18.13 \text{ kg/s}$$

where: ΔT = temperature difference between inlet and outlet hot water. It is assumed that the inlet temperature is 40°C (from condenser) and outlet temperature is 30°C, so $\Delta T = 10°C$.

For the 5 greenhouses, the total hot water requirements Q_{gt} are:

$$Q_{gt} = 18.13 * 5 = 91 \text{ kg/s}$$

The hot water from the condenser is about 160 kg/s at a temperature of 40 °C (Fig. 4.2). The hot water requirements are 90 kg/s for greenhouses heating. The hot water from the condenser is therefore more than sufficient for greenhouse heating purposes. The extra hot water (70 kg/s) may possibly be used for aquaculture.

4.5.2. Woolwashing

As discussed previously it is proposed to use the water from the separator to supply the necessary heat for the district heating system. For this purpose about 60 kg/s of the 90°C hot water is needed. As shown in Fig.4.2 the rate of water flow from the separator station is about 271 kg/s are left over when the needs of the district heating are taken care of. It is suggested that this water may be used for woolwashing drying purpose.

As shown in Fig. 1.1 the washing and drying of wool is assumed to take place at optimum temperature of about 100°C. This is somewhat higher than the available water from the separator, but in a place like Naqu where water boils at a temperature of about 86°C it seems unlikely that is done at a temperature above that.

The 90°C water coming from the separator contains dissolved minerals which in all likehood render it unsuitable for washing. The woolwashing water will therefore be heated in a heat exchanger just like the district heating water. By proper heat exchanger design it is possible to supply 80 - 85°C water suitable for woolwashing.

4.5.3. Binary Cycle Power Production

It is mentioned previously, in section 3.3, that it is possible to use the water from separator for binary power production. This cycle is shown in Fig. 3.2. In order to get an idea about the possible power production by this process an analysis has been carried out with isobutane as the secondary fluid with the following results:

Inlet temperature of geothermal fluid, °C	90.0
Outlet temperature of geothermal fluid, °C	40.0
Inlet temperature of binary fluid (from condenser), °C	20.0
Outlet temperature of binary fluid (saturated vapor), °C	57.0
Heat energy extracted from geothermal fluid, kJ/kg	209.5
Circulated binary fluid, kg/kg geothermal fluid	0.542
Isentropic output in binary turbine, kJ/kg geothermal fluid	26.6
Thermodynamic efficiency of binary cycle, %	12.7
Cross turbogenerator output, assumed 70 % efficiency, kJ/kg	18.6
Overall binary efficiency, %	8.9
Cooling water needed, T = 6°C, kg/kg geothermal fluid	7.6

Pumping energy, binary fluid, kJ/kg	1.0
Pumping energy, cooling water, kJ/kg (est.)	2.5
Other own energy needs (assumed), kJ/kg	1.0
Net turbogenerator output, kJ/kg	14.1
Net output efficiency, %	6.7

With the available geothermal fluid flow of 211 kg/s the net power output of the binary unit is about 2975 kW or about 50 % more than the steam turbine power output discussed earlier. This possibility might therefore be worth a closer look in the future.

The binary cycle is characterized by the tremendous quantity of cooling water needed, in this instance over seven times the rate of geothermal fluid. This makes it necessary in many instances to use cooling tower to achieve the necessary cooling.

5. ECONOMIC ANALYSIS

5.1. General

The economics of this project are difficult to evaluate because of the many uncertain factors involved. The ways and considerations are also different from one country to another and are based on different situations. Generally, one may say that regardless of economic considerations of this project it is justified for social development purposes and because of the benefits it will bring to the people in China. In this section, the author would like to study the project economic analysis from the technical and economic point of view based on the local situation.

5.2. Factors of Cost

5.2.1. Scale Effect

In the case of geothermal power generation, the costs are conventionally divided into two main components - energy supply cost and power plant cost. The power plant cost refer to the capital and operation cost of the power plant. The important impacts for capital cost are the so-called scale effect, the load factor and the thermodynamic efficiency. The scale effect says that a larger plant will tend to cost less per koliwatt than a smaller plant of similar type (Fig. 5.1). An approximate formula for this effect, which broadly applies to conventional thermal plants is (Ref. 12):

$$\text{Total capital cost} \propto \text{Kilowatt capacity}^{0.815}$$

It means,that if plant A has 10 times the capacity of plant B, its total cost would be about 6.5 times that of plant B and the cost per kilowatt of plant A would be about 65 % of that of plant B. With geothermal plants if the exploration cost were treated simply as capital expenditure, the scale effect of a geothermal plant would be greater than for a conventional thermal plant, and the formula would become something like:

$$\text{Total capital cost} \propto \text{Kilowatt}^{0.7}$$

That is to say, if plant A were 10 times the size of plant B, its total cost (including exploration) would be about 5 times as great, and its capital cost per kilowatt would be about 50 % of that of plant B. This formula, however, should be treated as indicative only since exploration cost can vary so widely from project to project.

If the exploration cost is not included, the formula would be more like:

$$\text{Total capacity cost} \propto \text{Kilowatt}^{0.875}$$

Thus, if plant A were 10 times the size of plant B, its total cost would probably be about 7.5 times as great, and its cost per kilowatt would be about 75 % that of plant B.

5.2.2. Well Temperature and Flowrate

The thermodynamic efficiency, discussed in section 3.6, is dependent upon the wellhead temperature and it is an important factor for the geothermal power production cost. At a certain installed capacity, the capital cost reduces as the wellhead temperature increases. This is so because less flowrate is required to generate the same amount of power from higher temperature fluids than from lower temperature fluids (Fig.5.2, Ref. 13).

The investment cost also varies inversely with flowrate of the geothermal wells. With larger flowrate fewer wells are needed and the total well costs are lower. The cost is much more sensitive to flowrate at lower temperature than at higher temperature because the thermal to electric conversion efficiency increases rapidly with temperature. For a constant fluid temperature, the power production potential from a well is proportional to flowrate (Fig. 5.3, Ref.13). It also can be defined by the formula (3.4):

$$P_e = W_{net} * Q$$

where, Q = total flowrate

If W_{net} is fixed, the power production is directly proportional to the flowrate Q.

As previously mentioned, well flowrate and fluid temperature are two of the most important resource parameters in the cost relationship. Since the properties of the Naqu geothermal reservoir are not well defined so far, it seems to be reasonable to assume that the parameters of all production wells for electric power generation are the same as those of well ZK 1005 and 1303 at a temperature of 112°C and pressure of 3 ata. The flowrate for existing wells may be increased by using a deep well pump or by slight reducting of the wellhead pressure. Production of new wells may be increased by larger diameters.

5.2.3. Load Factor

Since a large fraction of the costs associated with geothermal power are fixed costs related to the initial investments, the cost of power increase rapidly as the load factor decreases (Fig. 5.4, Ref. 13). For this reason efforts should be made to achieve as high a load factor as possible. The load factor for Naqu geothermal power plant is estimated as 0.68 (6,000 hours/year). This is considered reasonable in view of the present electricity shortage.

5.2.4. Well Costs

The power costs are directly related to the cost of the geothermal wells (Fig. 5.5, Ref.13). The effect of the well costs are much greater on lower quality (low temperature and flowrate) resources as previously pointed out. Since the temperature and flow are to a large extent determined by nature, and since power plant costs are not subject to wide variation, the well cost is probably the single most important factor of the economic viability of a geothermal resource. Generally,the mean production well cost is 4,000 RMB yuan/m (1 US dollar = 3.71 yuan) at a well depth of about 200 m in Tibet.

5.2.5. Uncertain Cost Factors

The main uncertain cost factors are the geothermal field potential and the intensity of scaling and deposits. The well site locations will influence the supply cost caused by pipeline mainly. Another factor is that if the fluid transmission lines are very long, large temperature and pressure drops will occur resulting in reduced output of the turbines. This influence is more important for the low temperature and pressure reservoirs than for high temperature and pressures.

The scale formation reduces the heat transfer coefficient in heat exchangers and reduces the efficiency of pipe lines and separators. Low heat transfer coefficients require larger heat exchangers which again increases the capital cost, as well as the operation cost.

5.3. Investment Estimate

5.3.1. Capital Cost

The investment cost per kilowatt is based on the power plant type, capacity and location. The cost standard is very different from place to place. For a geothermal project, the cost is influenced by many factors such as capacity and resource parameters mentioned in section 5.2 (Table 5.1). The investment for Yang Ba Jing Geothermal Power Plant is about

6,000 - 7,000 RMB yuan/kW in Tibet with a capacity of 3 MW. The capital cost per kilowatt varies widely from place to place because of the local construction condition and it is increased or decreased with the altitude and distance from Lhasa. From this point, the capital cost per kilowatt for Naqu power plant is estimated as high as 8,000 RMB yuan/kW with for a power plant of 2 MW (Table 5.2).

The district heating system design consists of improving the existing system.A single pipeline and house connections are already installed as mentioned in section 2. The investment cost for this subproject consists of building a new pipeline, a pumping station and a heat exchanger station. It is estimated that 2 million RMB yuan are needed (including hot tap water and public bath). The total investment is then estimated as 18 million RMB yuan (4.9 million US dollars).

5.3.2. Comparison with Solar and Wind Energy

Tibet is rich in solar and wind energy (Fig.5.6, Ref. 14), and as an example Lhasa is called "the sunny city". Small capacity solar panels and wind generators, 500 - 2,000 W, have been developed rapidly in recent years. Combined solar-wind systems and wind irrigation systems are under study in the center and northern parts of Tibet. It is well-known that Tibet is a large area with small population, where most of the people live in the south, south-east and center parts of the country along the Yaluzonbu river. Only about 30 % of the people live in the northern part, in the large grasslands area, mostly on animal farming. The small capacity solar panels and wind generators have certain advantages for the animal farmers since they are easy to dismantle and maintain. The main problems are that these units are too costly, although the price is going down, and they are available only for a small capacity. The large capacity solar power station and wind generator field can not be built for the next 10 years due to technological or economic considerations. The geothermal power is more competitive in comparison with solar and wind energy, even in spite of the low temperature and low thermodynamic efficiency. Other conventional energy resources such as hydropower, oil or coal, are not available.

5.4. Benefit Estimate

5.4.1. Production Cost of Power Plant

The production cost of the power plant is estimated based on the following preliminary parameters according to Tibet custom:

Capacity	2 MW
Total investment	16 million RMB yuan
Production wells (8 wells, 0.2 million yuan/well)	1.6 million RMB yuan
Load factor	0.68 (6,000 hours/yr)
Plant capital	13.6 million yuan
(Plant units costs are calculated by taking 85 % of the investment, this is called the plant capital)	
Fixed running cost (life time: 25 yrs)	10 % of plant capital

The load factor is estimated as 0.68 (6,000 hours/yr).This seems to be reasonable because the geothermal power will serve as base load (Table 5.3).

5.4.2. Income of Power Plant

The income of the power plant is based on the electricity production and the selling price. If the electricity production is constant by a certain load factor, the income price is a direct function of selling price (Table 5.4). Table 5.4 shows that the most attractive income value is reached at a selling price of 0.3 or 0.4 yuan/kWh with capacity 2 MW and a load factor of 0.68. Presently as mentioned before, there is a diesel generator power plant in Naqu town, running at a production cost of 0.75 yuan/kWh. The selling price is 0.4

yuan/kWh. The local government subsidizes the selling price at the rate of 0.35 yuan/kWh. Comparing with this case, the selling price of geothermal power plant may be reasonable and competitive at 0.3 yuan/kwh. The income is about 2.9 million yuan/yr and about 1.18 million yuan net benefits can be gained from selling the electricity (Table 5.5).

It is assessed that 3,500 MWh of electricity produced annually by small diesel generators owned by the industry and commercial activities today, will be discontinued when the geothermal plant become operational. This will result in savings of 2.6 million yuan annually (0.75 yuan/kWh). It is assumed that municipal diesel power plant will be operated approximately 3 hours per day as presently as a peak power supply, so no change in the diesel power plant operation cost is assumed.

5.5. Social Benefit

Geothermal exploration in Tibet dates back to year of 1972. In 1976, the first 1 MW geothermal turbine generator was installed with single flash system in Yang Ba Jing Geothermal Power Plant, which is 90 km northwest from Lhasa. So far, 5 geothermal turbine units have been commissioned with the total capacity of 13 MW and electricity production of about 4,380 MWh per year (the total electricity production of Lhasa power network is about 110,000 MWh/yr). The second geothermal power plant in Yang Ba Jing geothermal field is under construction and additional 10 MW generating capacity is planned to be installed in 5 years. Now the installed capacity of geothermal power is about one third of Lhasa power network (Table 5.4). But the geothermal utilization is practically all in the electric power field although there are some geothermal heating greenhouses in Yang Ba Jing. The geothermal energy multi-purpose application seems very attractive by cascading of geothermal energy, especially in the northern part of Tibet. As mentioned in section 2, people living there have to burn dry yak dung, grass root and bush for heating their houses and for cooking due to shortage of conventional energy and fuel. This causes serious environmental problems such as grasslands degeneration, soil exposure and transformation into desert. This is the ecological cycle, that if one thing goes wrong, everything seems to go wrong and this has really happened in some places. The Naqu geothermal project is not only conceived to meet the urgent electrical needs in Naqu, although it is a new stage of geothermal development in Tibet. This project has three advantages at least: The first is that it can solve the electricity shortage to a certain degree. The second is the economic benefit from the sale of electricity production. The third is that it can save money by using geothermal energy instead of oil fired boiler heating and diesel generators. By rough estimate, 3,333 tonnes diesel oil and 2.7 million yuan can be saved (competitive fuel is the oil based on the hospital heating system design). This can be defined as follow:

$$\begin{aligned} E &= Q * L * 8760 * 3600 \quad \text{GJ} \qquad (5.1) \\ &= 82{,}116 \quad \text{GJ} \end{aligned}$$

where, E = the energy of the heating system GJ

L = 0.65, the load factor. It may be reasonable to compare with the load factor of 0.5 in the Reykjavik district heating system. The design temperature in Naqu is much lower than in Reykjavik and the heating duration is longer (Fig. 5.7, Ref. 15).

Q = energy requirements for hotel and hospital heating system, kW

The oil requirement is:

$$\begin{aligned} R_o &= E * 10^3 / v * \hat{U}_1 * \hat{U}_2 \quad \text{tonnes} \qquad (5.2) \\ &= 3{,}333 \text{ tonnes} \end{aligned}$$

where, R_o = oil requirement tonnes
v = 44 MJ/kg, the lower heating value of typical heating oil (Ref. 1)
$\hat{U}_1$ = 0.7, fired boiler efficiency (Ref.1)
$\hat{U}_2$ = 0.8, the plateau burning efficiency (estimate)

The oil price in Naqu is 0.8 yuan/kg, which means that the elimination of oil firing will bring savings of 2.7 million yuan per year.

The total saving from the district heating and diesel generators are 5.3 million yuan. Comparison of the annual cost of the system gives:

1) cost of using present system, yuan/year		
operation cost of small diesel generators		2.6 million
operation cost of fired heating		2.7 million
Total		5.3 million
2) cost of geothermal system		
power plant, yuan/year	1.7 million	
district heating, yuan/year (installation of new main)	0.2 million	1.9 million
3) net earning of the project, yuan/year		3.4 million

In order to the benefit obtained directly from the project, there ares other important aspects to be considered. It makes people aware of the fact that using geothermal energy may be a solution to the conventional energy shortage. The economic and living conditions will be improved with geothermal application. It shows a great and hopeful future to people: it is possible to gain more and more benefit from other industry if sufficient electricity is generated from geothermal power plant.

6. CONCLUSIONS

So far, the author has discussed the project purpose, design consideration, heat demand and energy balance, system design, and economic analysis in this paper. It seems attractive and competitive compared with other new energy resources and fossil fuels. The main point from technical and economic point of view are expressed as follow:

(1) The total investment of the project is 18 million RMB yuan, the net income is about 1.18 million RMB yuan, the net benefit is 3.36 million yuan. The investment and benefit are very sensitive to geothermal fluid parameter such temperature, pressure, flowrate and system load factors.

(2) This project is dependent on the field energy resources. If the final field report shows that the resources are sufficient for electric power purposes, there is a potential for using the geothermal fluids for increasing the generating capacity and the heating area in the future as a second development phase.

(3) The low temperature geothermal fluid has been used in district heating, agricultural field and other aspects successfully in many countries, Iceland, France, U.S.A, etc. For generating purposes, it still needs to be discussed. It is based on certain local conditions and energy requirements, although the thermodynamic efficiency is very low.

(4) There are some technical problems which need to be solved, such as the chemical behavior and environmental impact of the geothermal fluid, surface equipment selection, etc.

Geothermal applications in Tibet has developed rapidly in recent years even though there are many technical problems which need to be solved. Geothermal direct use is now only beginning. There is much works to be done and new fields to be researched. The author believes that geothermal energy will be of great benefit to the human race in the future.

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Table 1.1 Direct Use of Geothermal Energy World-Wide (from Ref. 1)

Country	Flow rate kg/s	Power MW	Energy GWh	Load %
Chian	3,540	393	1,945	56
France	2,340	300	788	30
Hungary	9,533	1,001	2,615	30
Iceland	4,579	889	5,517	71
Italy	1,745	288	1,365	54
Japan	26,101	2,686	6,805	29
New Zealand	559	215	1,484	79
Romania	1,380	251	987	45
Soviet Union	2,735	402	1,056	30
Turkey	1,355	166	423	29
United States	1,971	339	390	13
Other	1,965	142	582	47
Total	57,803	7,072	23,975	

Table 2.1 Temperature data of Lhasa og Kashgar (from ref. 3)

Table 2.2 Data for two production wells at Naqu geothermal field (Ref. 16)

Well Number		ZK 1303	ZK 1005
Flowing Temperature	°C	109	107
Flowing Pressure	kg/cm^2 *	3.01	2.83
Flowrate	h/t	156.6	127.5
Depth	m	120	503

* absolute pressure

Table 2.3 Physical Parameters of the Naqu Geothermal Field (Ref. 17)

Name		Naqu
Elevation	m	4410
Surface Temperature	°C	61.5
Natural Heat Flow	kW	9,600
Volume	km^3	8.5
Thickness of Reservoirs	km	1.5
Geothermal Thermometer	°C	
T SiO_2		124
T NaK		166
T NaKCa		176
Storage Capacity	$cal*10^{18}$	0.9

Table 4.1 Properties of the Building Materials (from Ref.18, Ref. 19)

Material	Density	1/k W/(m^2°C)	
	kg/m^3	Chinese	Icelandic
Tar	1460	0.28	
Reinforced concrete	2400	1.55	1.7
Gravel concrete	2200	1.28	1.7
Fir	550	0.175	0.15
Brick	1700	0.755	0.15
(cement with sand)			
Cement mortar	1800	0.93	1.0
Outside wall plaster	1600	0.875	1.2
Inside wall plaster	1600	0.697	1.0
Tar paper	600	0.175	
Window glass	2500	0.755	0.8

Table 4.2 Thermal Transfer Coefficient k and Thermal Resistance m (from Ref.18, Ref. 19)

Building Element	k W/(m^2°C)		m W/(m^2°C)	
	Chi.	Ice.	Chi.	Ice.
Door	4.64	2.5		
Window on the outside wall, wood frame, double glass pane	2.7	3.2		
mi inside wall, floor, roof			0.112	0 13
m_d outside wall, roof			0.043	0 04

Table 4.3 k - Values of Wall, Roof, Floor in Chinese Building

Element	k W/(m^2°C)	Design Temp. °C
Wall	1.92	18 / -28
Roof	2.15	18 / -28
Floor	4.05	18 / -28

Table 4.4 Heat Loss of Naqu Hospital

Element	A m^2	k W/(m^2°C)	t_i °C	t_0 °C	T diff. °C	Q kW
Wall	2289	1.92	18	-28	46	202.2
Window	850	2.7	18	-28	46	105
Roof	2800	2.15	18	-28	46	276.9
Floor 1	447	4.05	18	-28	46	83.3
Floor 2	2353	4.05	18	-2	20	190.6
Air change* (0.8/h, 0.29 W/m^3°C)					46	209.2
Total						1068

* This value is based on Mr. Karlsson: Geothermal District Heating, The Iceland Experience. The net floor area is estimated 70 % of gross area of 4,000 m^2, 7 m high.

Table 4.5 Heat Loss of Naqu Hotel

Building Name	Volume m^3	Heat Demand W/m^3	Total Dema d kW
Building 1	34991	54.5	1906
Building 2	2800	54.5	152.6
Building 3	12040	54.5	656.5
Dining Hall 1	2040	54.5	111.2
Dining Hall 2	2040	54.5	111.2
Total	53911		2938

Table 4.6 Total Heat Demand of District Heating System

Name	Heat Demand kW
Hotel	2938
Hospital	1068
Total	4006

Table 4.7 Heat Demand of Power Plant Own Use

Building Name	Floor Area m^2	Height m	Volume m^3	t_d °C	Heat Demand W/m^3	Total kW
Workshop	600	15	9,000	46	54.5	490.5
Office	400	7.2	2,800	46	54.5	157
Residence	800	6.2	4,960	46	54.5	270.3
Total						918

Table 4.8 Hot Water Flowrate Needed for Naqu District Heating

Name	Q kW	T_d °C	m_h kg/s
District Heating	4,006	30	32
Power Plant	918	30	7.3
Hot Tap Water			
1. D.H.System	370	70	1.26
2. Power Plant	43	70	0.145
3. Public Bath	20.3	70	0.07
Total	5,357		41

Table 5.1 Mean Power Development Capital Cost in Tibet

Name	Capital Cost (RMB yuan/kw)		
Capacity (kW)	500 - 1,000	1,000 - 3,000	> 3,000
Hydropower	6,000	5,000	4,000
Geothermal Power		>10,000	6,000 - 7,000

Table 5.2 Power Production Cost

NAME	SINGLE FLASH		SINGLEFLASH + BINARY	
			Chinese equipment	Overseas equipment
Capacity (kW)	1,000	2,000	2,000+1,000	2,000+1,000
Total (10^6 yuan) Investment	12	16	23	26
turbine	1	2	4.36	7.36
production well	1	1.6	1.6	1.6
Plant Capital (10^6 yuan)	9.35	13.6	19.55	22.1
Electricity Production (MWh)				
3,000 hrs/year	3,000	6,000	9,000	9,000
4,400 hrs/year	4,400	8,800	13,200	13,200
6,000 hrs/year	6,000	12,000	18,000	18,000
Power Plant Own Use (%)	20	18	22	22
Electricity Sales (MWh)				
3,000 hrs/year	2,400	4,920	7,020	7,020
4,400 hrs/year	3,520	7,216	10,296	10,296
6,000 hrs/year	4,800	9,840	14,040	14,040
Total Cost (10^6 yuan)				
fixed running cost*	0.935	1.36	1.96	2.21
labor cost	0.4	0.4	0.4	0.4
total	1.335	1.760	2.360	2.610
Production Cost (yuan/kWh)				
3,000 hrs/year	0.56	0.36	0.34	0.40
4,400 hrs/year	0.38	0.25	0.23	0.27
6,000 hrs/year	0.28	0.18	0.17	0.2

* 10 % of total plant capital

Table 5.3 Lhasa Electric Power Network

Name	Capacity (kW)	Type	Operation Duration
La Jin Power Station	7,500	hydro	half load from 11 - 4
Xian Do Power Station	2,600	hydro	
Xi Jiao Power Station	3,440	hydro	4 - 11
Lhasa Power Plant	16,000	oil-fired	peak load from 11 - 4
Yang Ba Jing Power Plant	13,000	geothermal	base load
Total	42,540		

Table 5.4 Annual Income Estimate for Geothermal Power Development 10^6 RMB yuan/year (for power plant own use see Table 5.2)

Name	Single Flash Cycle					
Capacity (kW)	1,000			2,000		
Selling Price (yuan/kWh)	0.2	0.3	0.4	0.2	0.3	0.4
Production hours						
3,000	0.477	0.716	0.954	0.979	1.468	1.957
4,400	0.7	1.05	1.40	1.435	2.153	2.870
6,000	0.954	1.431	1.908	1.957	2.952	3.914

	Singleflash + Binary Cycle					
	Chinese equipment			Overseas equipment		
Capacity (kW)	2,000 + 1,000			2,000 + 1,000		
Selling Price	0.2	0.3	0.4	0.2	0.3	0.4
Production hours						
3,000	1.404	2.106	2.808	1.404	2.106	2.808
4,400	2.059	3.089	4.118	2.059	3.089	4.118
6,000	2.808	4.212	5.616	2.808	4.212	5.616

Table 5.5 Comparison of Net Annual Earnings 10^6 RMB yuan

Name	Single Flash Cycle					
Capacity (kW)	1,000			2,000		
Selling Price (yuan/kWh)	0.2	0.3	0.4	0.2	0.3	0.4
Production Hours						

	Singleflash + Binary Cycle					
	Chinese equipment			Overseas equipment		
Capacity kW	2,000 + 1,000			2,000 + 1,000		
Selling Price (yuan/kWh)	0.2	0.3	0.4	0.2	0.3	0.4
Production Hours						
3,000	-0.983	-0.281	0.421	-1.404	-0.702	0
4,400	-0.309	0.721	1.750	-0.721	0.309	1.339
6,000	0.421	1.825	3.229	0	1.404	2.808

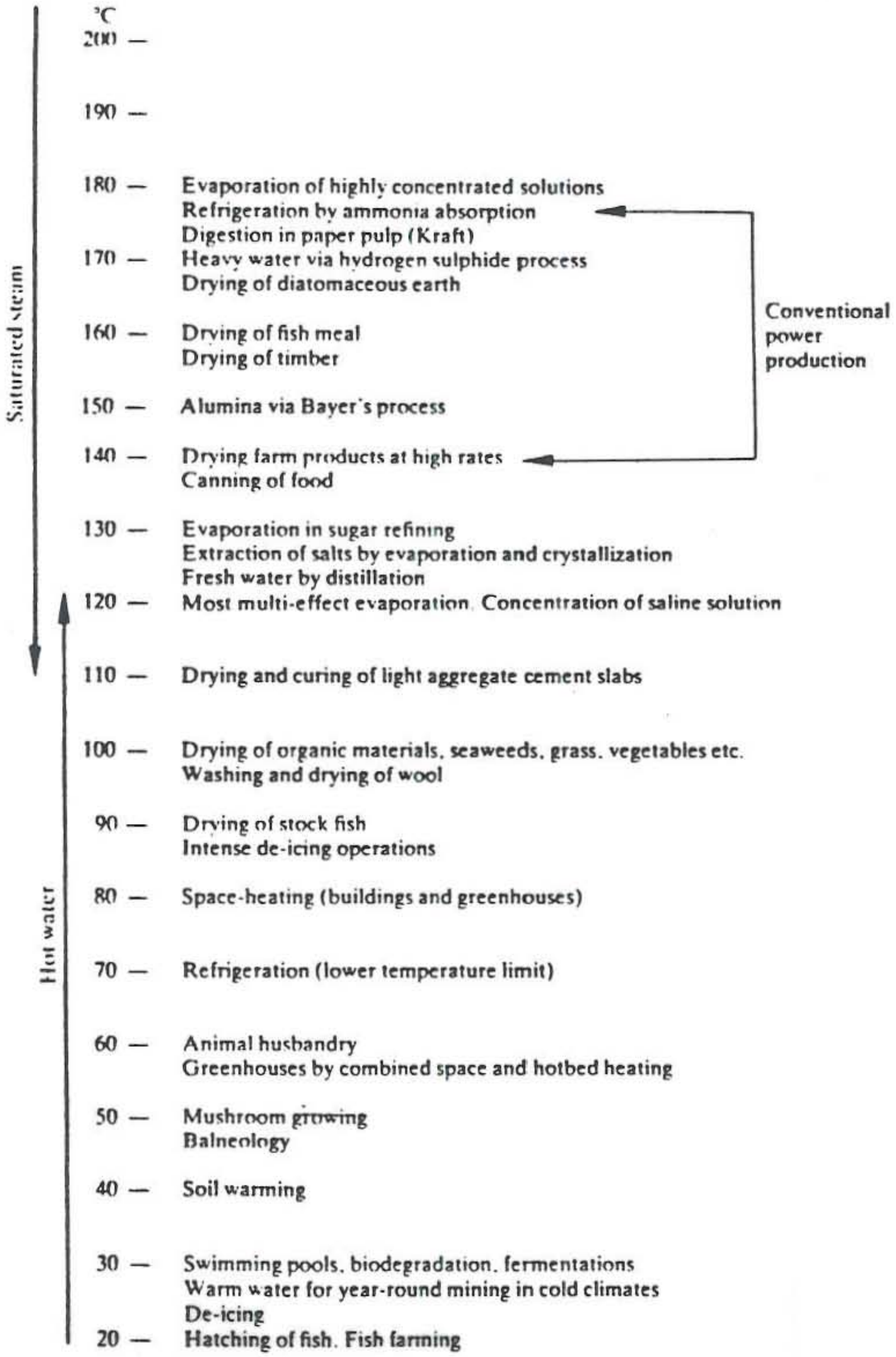


Figure 1.1 The Lindal Diagram

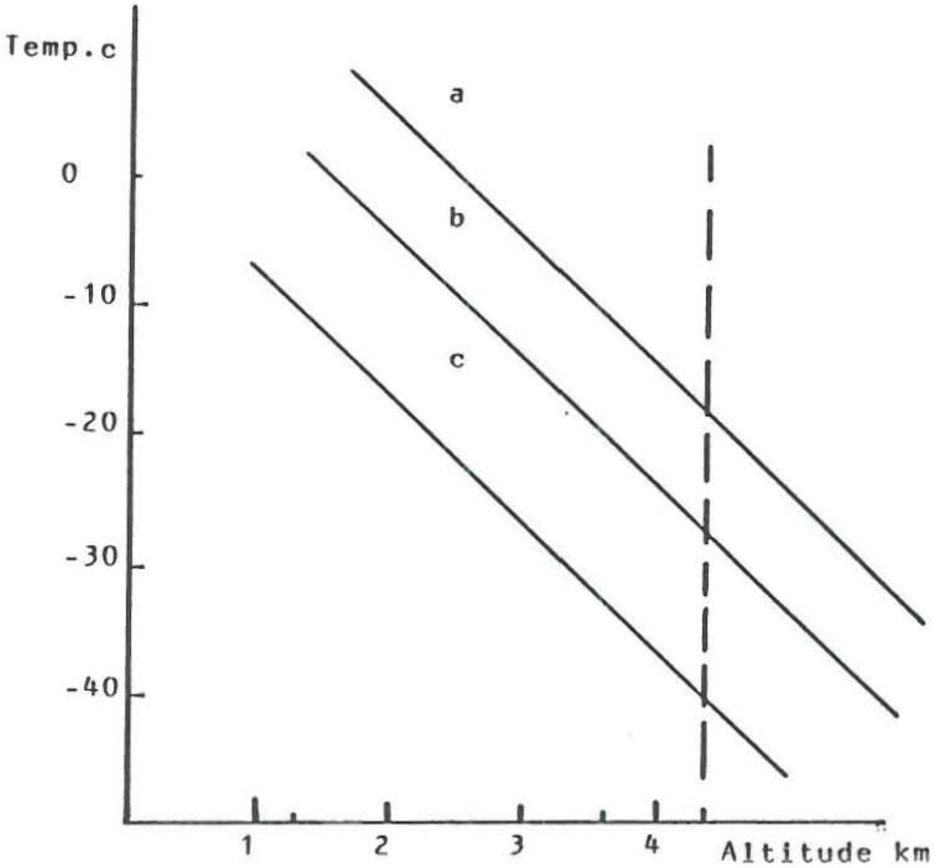


Figure 2.1 Atmospheric Temperature Versus Altitude

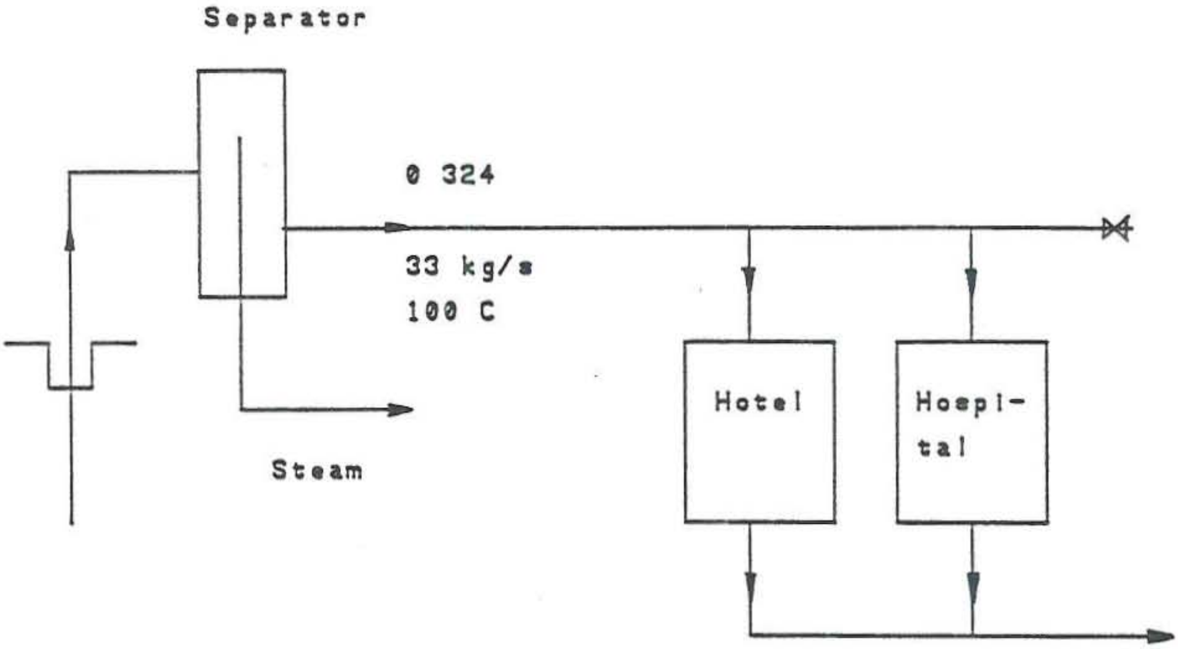
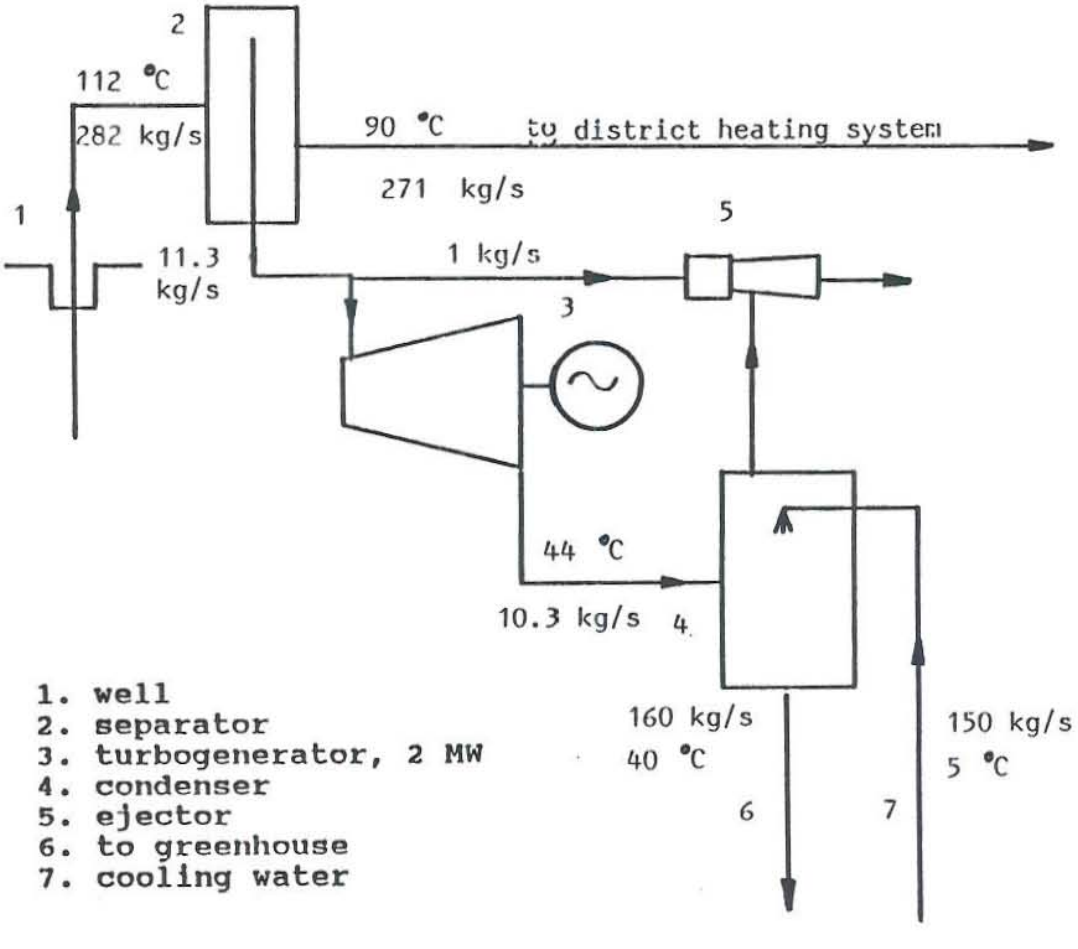


Figure 2.2 The Existing Heating System Flow Diagram



1. well
2. separator
3. turbogenerator, 2 MW
4. condenser
5. ejector
6. to greenhouse
7. cooling water

Figure 3.1 Single Flash Cycle Flow Diagram

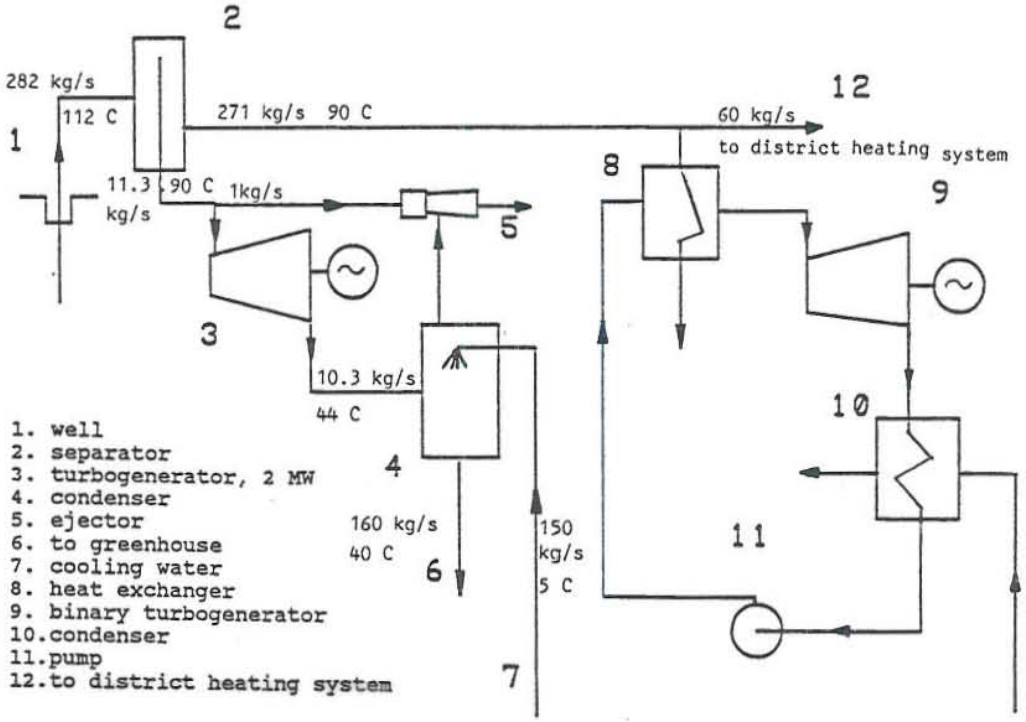


Figure 3.2 Single Flash-Binary Cycle Flow Diagram

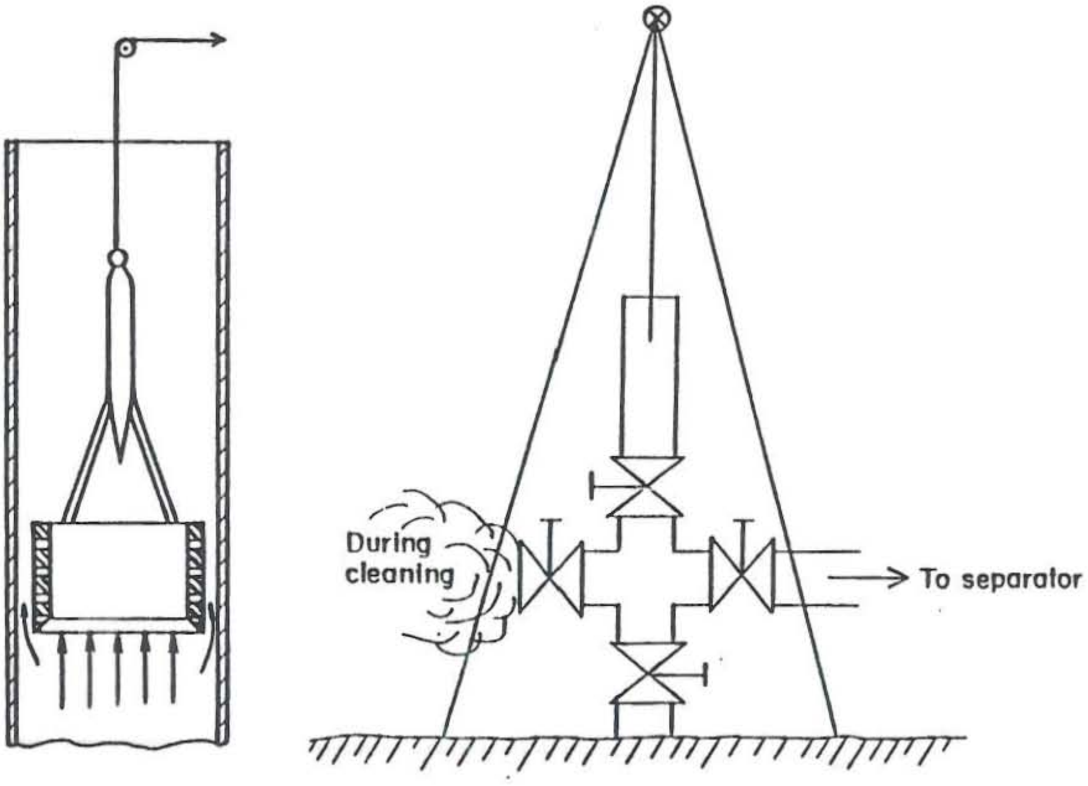


Figure 3.3 A Sketch of the Cleaning Device for Removing Calcite from Wells in Yang Ba Jing Geothermal Power Plant (from ref. 4)

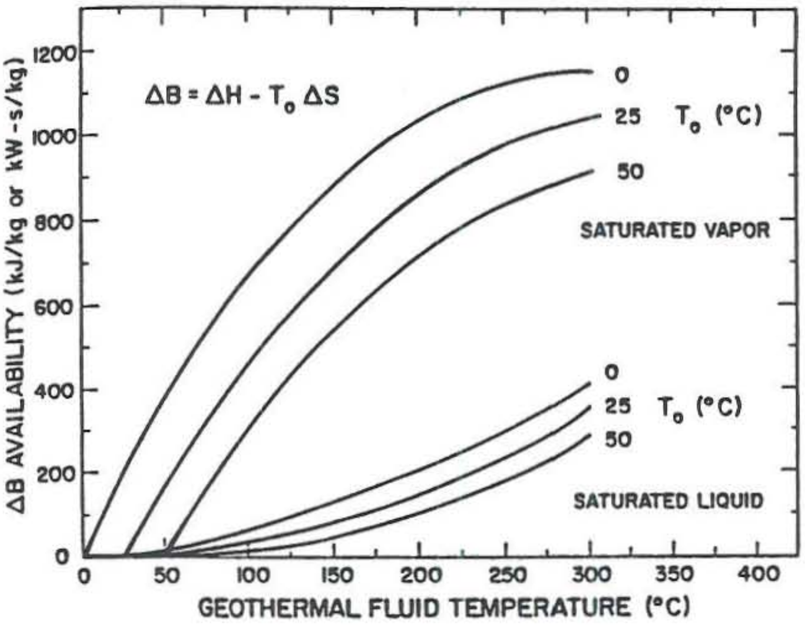


Figure 3.4 Maximum Available Work from A Saturated Liquid or Vapor Water Source (from ref. 5)

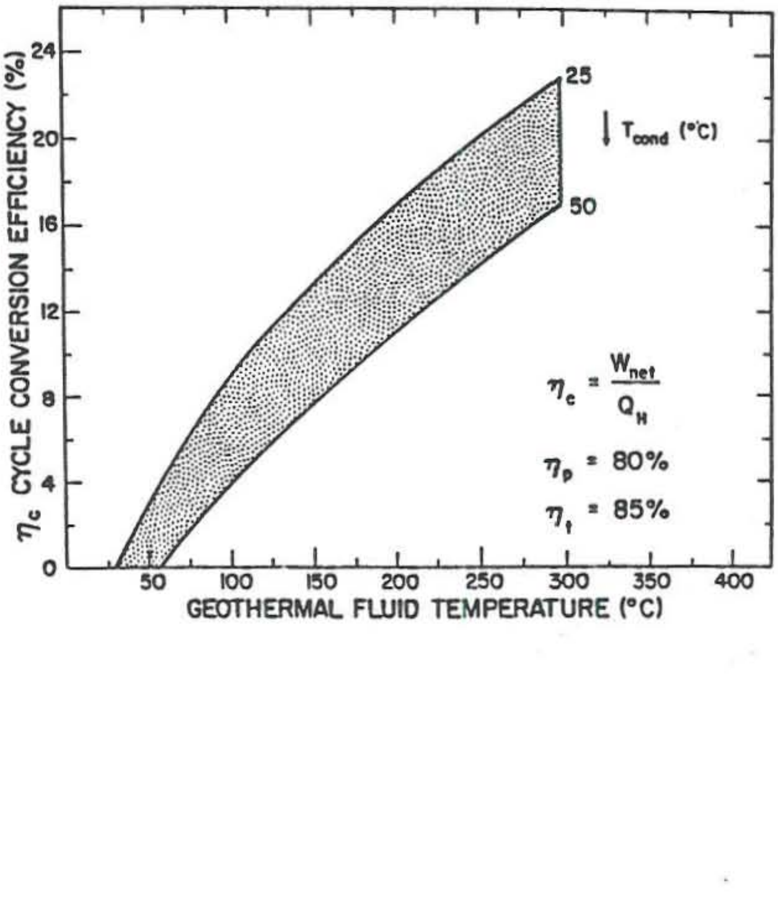


Figure 3.5 Typical Range of Anticipated Cycle Conversion Efficiencies for Geothermal Power Plant (from ref 5)

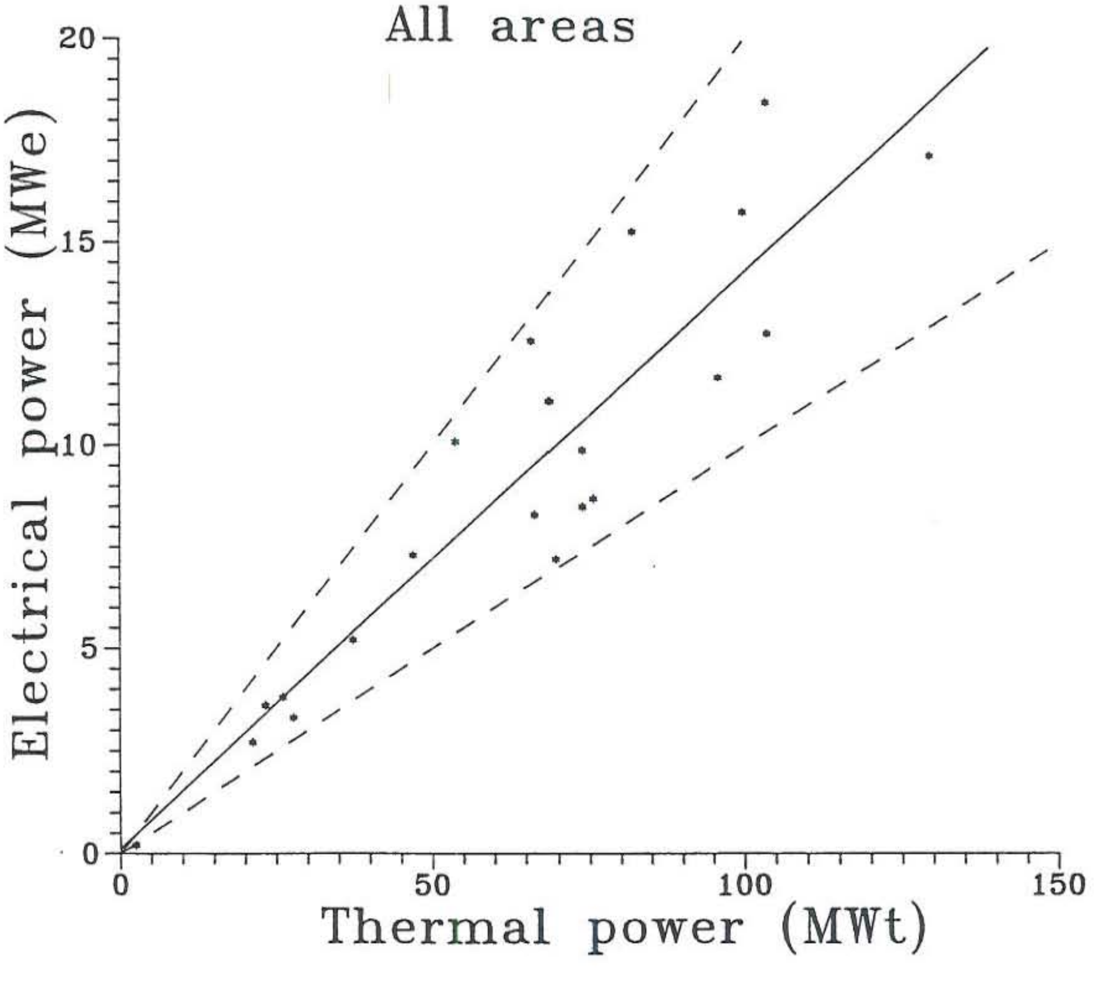
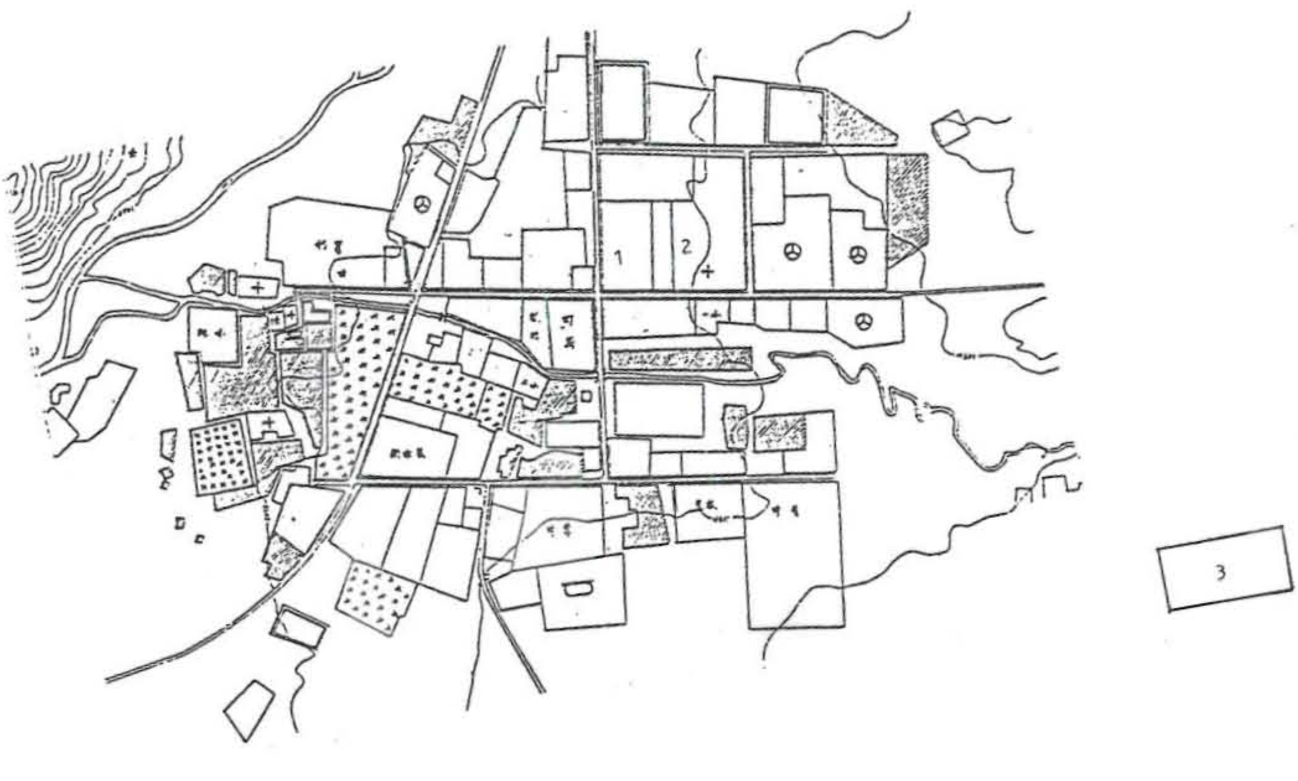
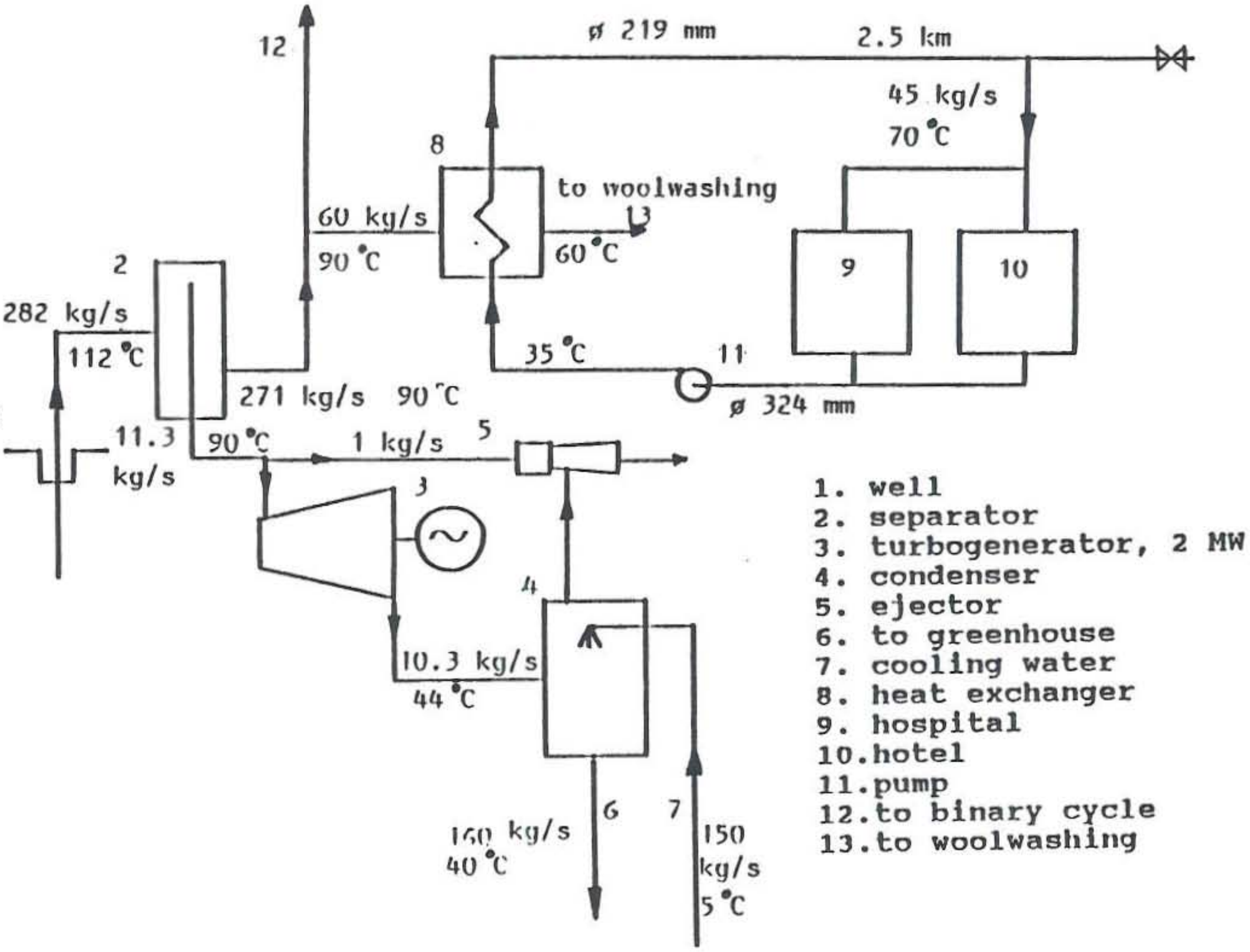


Figure 3.6 Thermodynamics Efficiency of Geothermal Wells World-wide (from ref 6)



1. hotel
2. hospital
3. geothermal field

Figure 4.1 Map of Naqu Town



1. well
2. separator
3. turbogenerator, 2 MW
4. condenser
5. ejector
6. to greenhouse
7. cooling water
8. heat exchanger
9. hospital
10. hotel
11. pump
12. to binary cycle
13. to woolwashing

Figure 4.2 Flow Diagram of the Multi-purpose Project

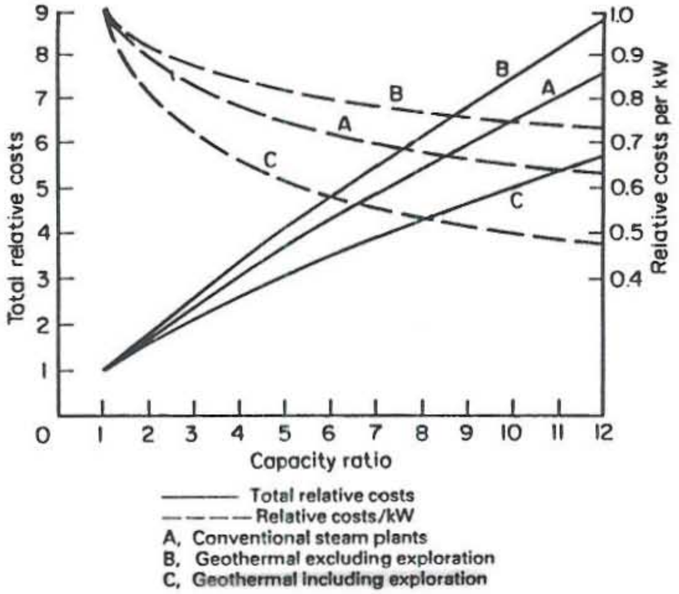


Figure 5.1 Approximate Cost Scale Factor (from ref. 12)

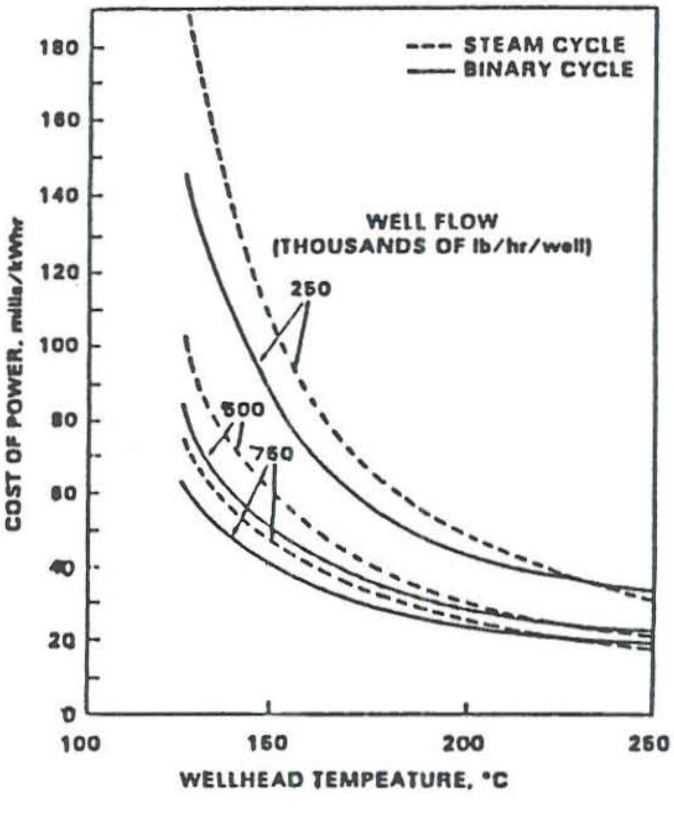


Figure 5.2 Effect of Temperature on Power Cost (from ref. 13)

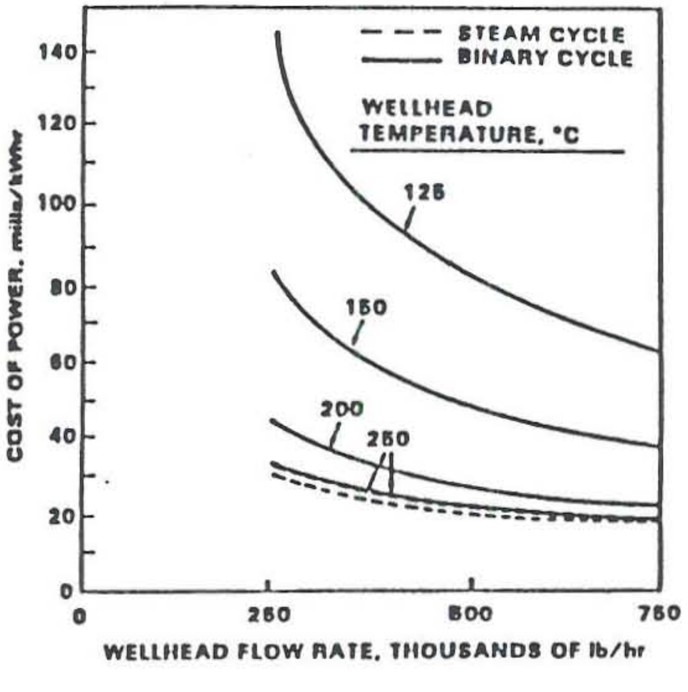


Figure 5.3 Effect of Flowrate on the Cost of Power (from ref. 13)

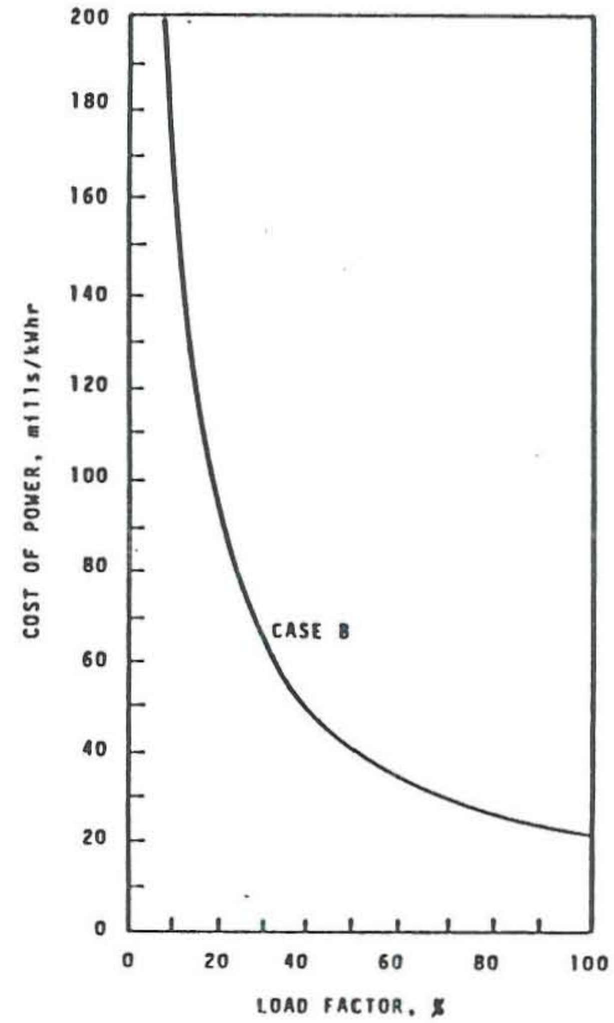


Figure 5.4 Effect of Load Factor on Unit Cost (from ref 13)

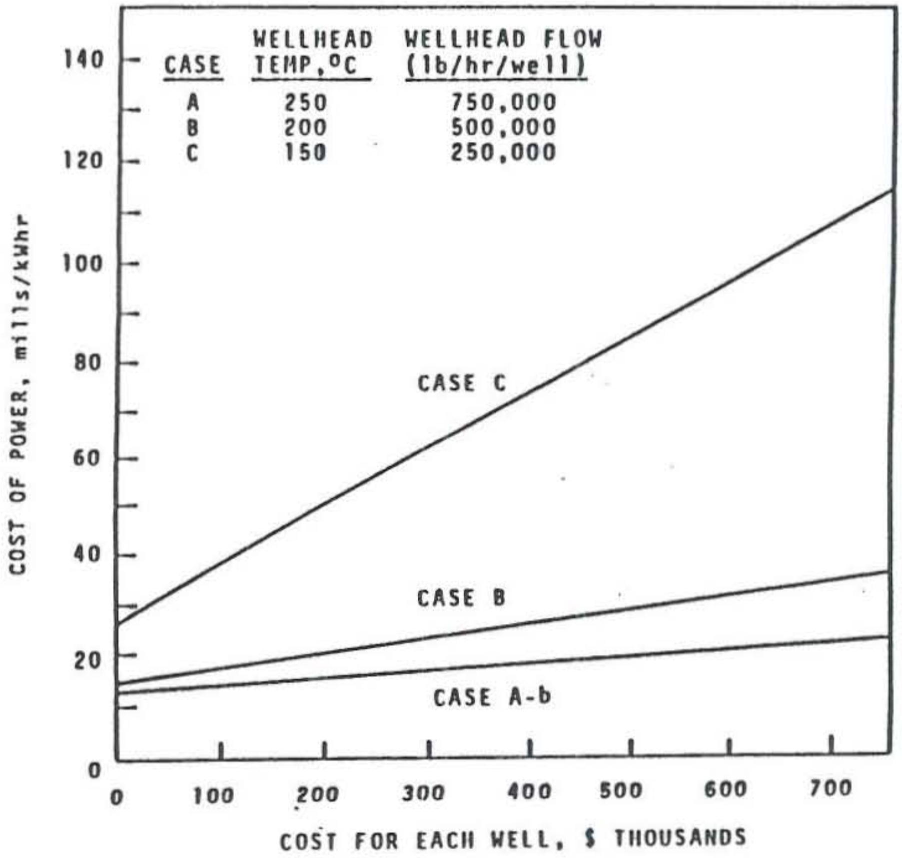
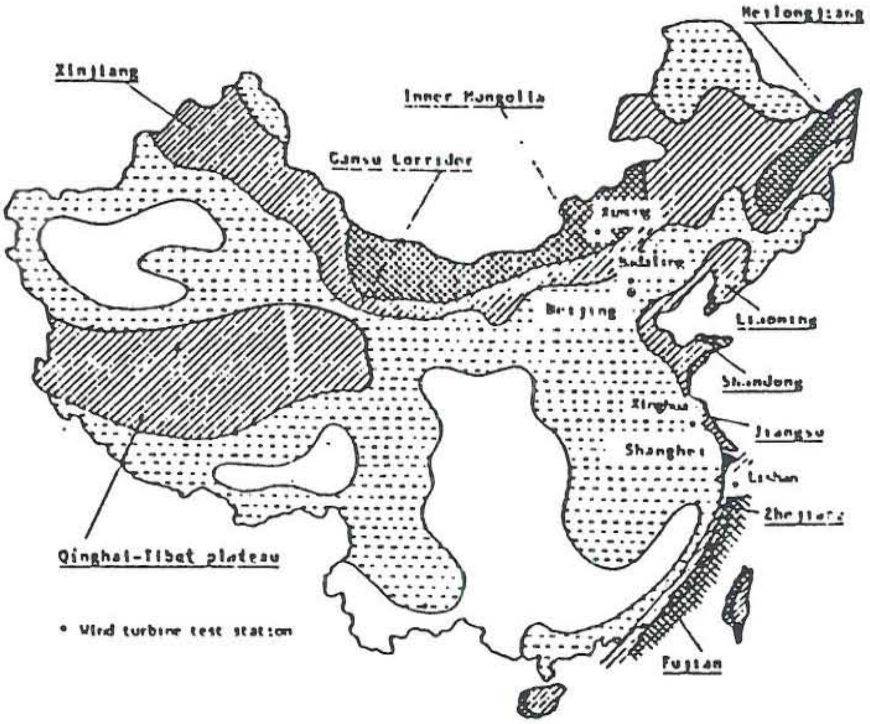


Figure 5.5 Effect of Well Cost on the Cost of Power
(from ref. 13)



The criterion of division

wind potential region	high ▩	moderate ▨	marginal ░	poor ☐
time duration above wind speed of 3 m/s (hours/year)	>5000	5000 - 4000	4000 - 2000	< 2000
time duration above wind speed of 6 m/s (hours/year)	>2200	2200 - 1500	1500 - 500	< 500
wind energy density (W/m^2)	>200	200 - 150	150 - 50	< 50

Figure 5.6 Four Wind Potential Region in China (from ref. 14)

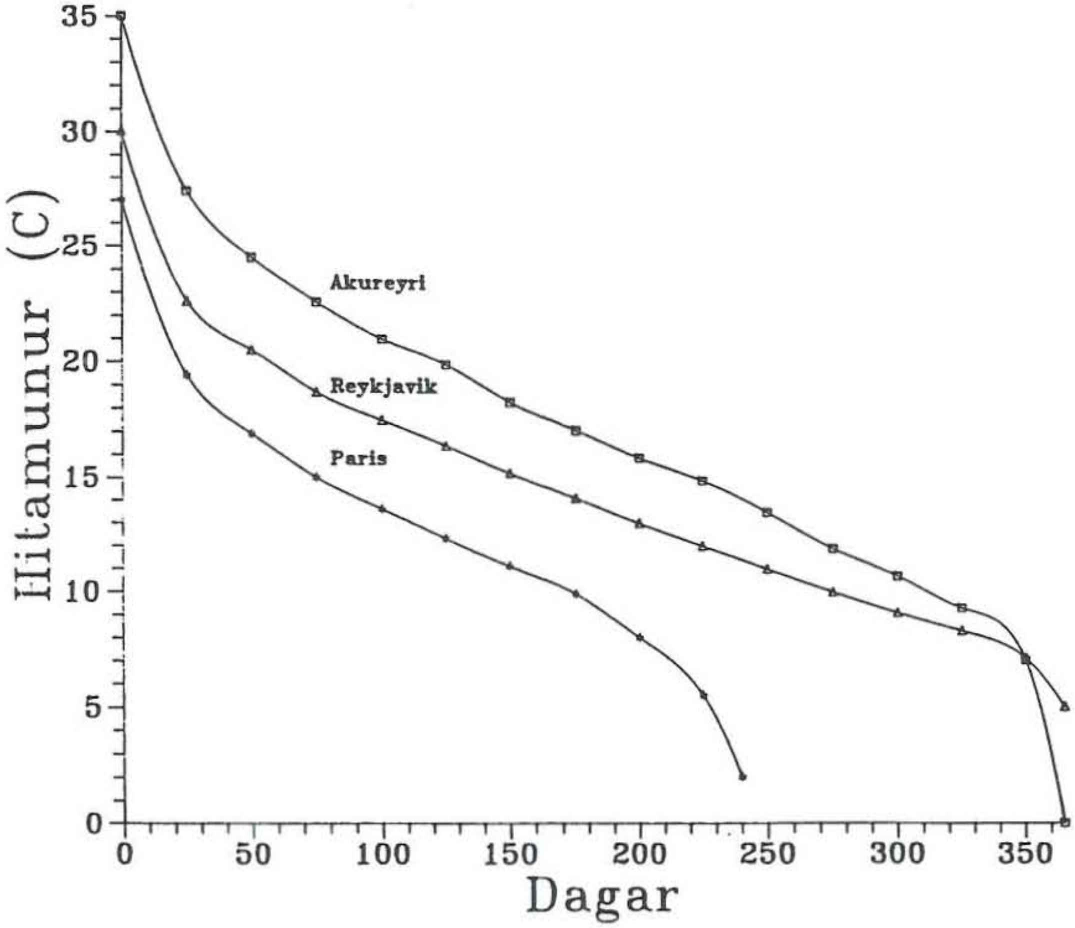


Figure 5.7 District heating System Load Curve of Reykjavik, Akureyri, Paris (from ref. 15)