Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Feasibility Study of Geothermal Utilization in Yangbajain Field of Tibet, China

Caixia Sun

No.A2, Lishuiqiao, Chaoyang District, Beijing, 102218, P.R.China

susan616128@hotmail.com

Keywords: feasibility study, geothermal, power cycle, district heating, IRR, sustainability

ABSTRACT

This study investigates the feasibility of renewable energy utilization in Tibet, China. Based on the available energy assessment and market analysis, a technical and economic feasibility study is carried out on geothermal development and utilization of Yangbajain field with the objective of solving both electricity shortage and lack of space heating in order to improve living conditions of the Tibetan people.

The technical feasibility study contains thermodynamic models of proposed different power generation scenarios and long distance district heating system to analyze and optimize each scenario by using EES and Matlab programs. The four alternative scenarios optimized for new power plant design are double flash cycle (Scenario 1), hybrid single flash and ORC cycle with isopentane as the working fluid (Scenario 2), pure ORC cycle with isobutane as the working fluid (Scenario 3), and a hybrid single flash and Kalina cycle (Scenario 4). The conceptual design of district heating system with about 90km distance from Yangbajain to Lhasa is carried out as well. The results indicate that all power cycles are technically feasible at different efficiencies and that the district heating system can be implemented with appropriate design and construction considerations. A financial viability evaluation is performed for all scenarios using engineering economic Present Worth (PW) value analysis method with the objective to determine the Internal Rate of Return (IRR) of each system. The optimum power cycle scenario is Scenario 1 with IRR value of 31.84%, followed by Scenario 2 with IRR value of 22.15%. The district heating system has a low IRR value of 3.13% due to the high investment cost of a long distance transmission pipeline. However, as part of an entire system of CHP power plant, the optimum system can yield 8.92% IRR value at pure commercial investment level. Since it will be a subsidized program from the central government, it can reach 10.78% of IRR value without incurring loan interest payments. If the expected IRR of the investment company is 10.00%, it proves this project is economically feasible.

1. INTRODUCTION

Tibet, as the second largest Autonomous Region in China, is located at main section of Qinghai-Tibet plateau, the southwest frontier of China. The total area is about 1.22 million km^2. Tibet lags behind other regions or provinces in many areas, including economic strength, literacy rates, life expectancy and average per-capita income; which is under \$250 a year in rural areas. However, since recent implementation of reforms and increasingly open relations with China, the region's economy has been developing, the society has been stable, and the living standard has been improving. The central government and local government are making great efforts to ameliorate conditions in Tibet. However, there are still 42% of the population that have no access to electricity. The application of space heating systems is still very old. Currently only 10% of the construction has a heating system, which is generally a coal burning boiler system. (Andre 98-99). In order to improve the local people's quality of life, the central government has decided to support the new energy projects to solve these basic problems in the period of “11th Five Year Plan” (2005-2010) and “12th Five Year Plan”(2011-2015).

2. ENERGY ASSESSMENT AND MARKET ANALISYS IN TIBET

2.1 Energy Assessment in Tibet

Tibet is weak in conventional energy resources, but rich in renewable energy. The total coal reserves, including explored and potential, is no more than 0.3 billion tons. The potential of oil resources have not yet been proven. However, the potential of hydropower resources is 200GW, accounting for 29% of the total amount energy needed for the whole country, and the country's largest energy resource. Therein, potential hydropower sites that could accommodate plants with more than 500kW capacity is about 110 GW, accounting for 25% of the total amount of the whole country's energy requirements. Wind and geothermal energy are also abundant. The geothermal resource potential for electricity generation is about 800 MW, and the potential of wind energy is 93 billion kWh. The solar energy resource in Tibet is the most greatest of all provinces or regions in the country. The radiation duration per year totals more than 3000 hours in many areas, and the energy capacity of radiation is around 6000-8000 MJ/m^2/year. In addition, Tibet is also rich in biomass energy resources. The total amount of forest residue amounts to 2.7 million ton coal equivalent, ranking the first in the country. The annual production of dry dung amounts to 1.7 million ton coal equivalent, which is the primary fuel in the rural areas (Zhen, 2006).

2.2 Energy Market Analysis in Tibet

According to the present energy potential and utilization status, the energy market in Tibet is still under exploration. There is a serious electricity shortage in the Lhasa area which has a very limited network output capacity, especially during winter. This is severely affecting the overall economic development of the region. Moreover, the natural environment is progressively being damaged by increasing forest cutting and use of animal waste for energy. Except for a few major cities (Lhasa, Xigaze, Nagqu), the 2 million inhabitants of Tibet live in small rural centers scattered over a surface area of 1.5 million square kilometers at an average altitude of more than 4,000 meters. Due to such severe geographic and climatic conditions, communication is extremely difficult and consequently electricity distribution in Tibet is still limited.

Although fossil fuels are costly to import into the region, the consumption is growing and will continue to grow in the future by necessity, causing future stress to the overall economy and the very fragile environment of the Tibetan plateau. Further development of the hydroelectric potential might not result a cost-effective option with the current technology, due to Tibet's environmental and socio-economic conditions. Wood and animal excrement are to be preserved for ecological reasons.

Tibet is potentially rich in geothermal resources for both power generation and direct uses. In fact evidences of thermal anomalies in the shallow crust (thermal spring, hot grounds, and steaming vents) are scattered throughout Southern and Central Tibet. Shallow exploration wells drilled in the past by the Regional Government in several locations have yielded fluids of potential interest, both for direct uses and electricity generation. It is believed that geothermal energy could account for the majority of Tibet's energy needs.

The power generation structure is shown in Figure 1. It shows that the majority of the power is supplied by hydro power which makes up 87.8% of total supply. However, the total electricity has not been able to meet the local demand ever since. There are 4,850 villages, 0.21 million families and 1.1 million people without power supply (Zheng Keyan, 2002).

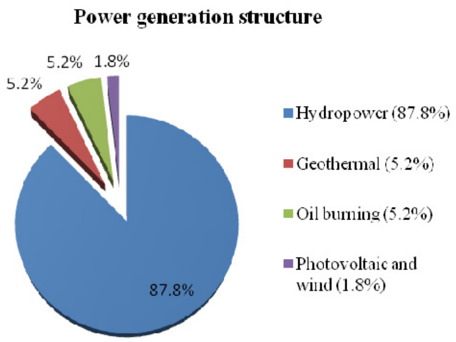

Figure 1: Power generation structure in Tibet

2.3 Background of Proposed Project

According to the energy utilization status, 42% of the population still has no access to electricity in Tibet, and only 10% of the buildings in Lhasa have heating systems. The living standard of local people is far behind the other provinces or regions.

Tibet as an important part of the country, the Central Government attaches importance to improving the standard of living of local people and developing the whole region. Energy supply as stated before is the most significant issue related to the regional development not only for the economy but also for the people's living quality.

In a long term development point of view, the hydro power and the geothermal energy will be the focus of future large scale project construction. The energy construction project as the basic solution to improve the local people's living level will be the subsidized program which continues to be supported by the central government. The proposed project is to make comprehensive use of Yangbajain geothermal potential to meet the power and space heating demand. The feasibility study is discussed in following chapters.

3. TECHNICAL FEASIBILITY STUDY OF YANGBAJAIN GEOTHERMAL POTENTIAL

3.1 Evaluation of the Present Geothermal Utilization

The most important geothermal utilization in Tibet is Yangbajain geothermal power plant built in 1970's. The power cycle applied in the existing power plants is double flash cycle. There were about 18 wells with an average depth of 200m tapping the upper water-dominated reservoir. The power plants were constructed in two parts: the capacity of the southern plant is 10MWe, consisting of 3 units each with 3MWe capacity and a 1MWe testing unit which was retired relatively quickly. The capacity of northern plant is 15.18MWe, consisting of four units each with a capacity of 3MWe and one 3.18MWe unit. Therefore, the total capacity of the power plants is 24.18MWe. However, the power plants have already been in operation for almost 30 years, the equipment is old or at very low efficiency. The real power output now is just around 15MWe. (Japanese International Cooperation Agency ,2002)

The initial working condition of the cycle is as follows: the geothermal water temperature is 145 ºC at wellhead. The inlet pressure of geothermal steam at first stage is 1.82bar, and the temperature is 115 ºC; the second stage inlet pressure is 0.54bar and the temperature is 81 ºC. The exhaust pressure is 0.10bar. Total geothermal production is about 3000m3/h. The discharging geothermal brine from the power plants is at the temperature of 80-90ºC. Most of the water has been discharged into the local Zangbuqu River. It has been a serious pollution due to the chemical component with fluoride, boron, etc.

3.2 New Power Plants Design Concept and Methodology

According to the reservoir assessment, new power plant conceptual design is carried out here. The main objective is to make sustainable utilization of both the upper and lower reservoir so as to meet the increasing power demand as well as the space heating need in Lhasa. Three basic power generation cycles are taken into account. The combined hybrid system concept is applied in conceptual design. Based on double flash cycle, ORC cycle, and Kalina cycle three general power generation types, four different alternative scenarios are carried out to make the thermodynamic and optimization analysis with the objective to get the best solution with both concerns of power generation and district heating.

This work includes the thermodynamic model calculations of each proposed scenario, the thermodynamic properties of each state of the cycles, the system optimization and performance analysis, and the examination of variations of fundamental characteristics of the cycles. In the performance and optimization analysis, optimum flashing pressures are determined in double flash cycle, the separation pressure of topping flash cycle and evaporation pressure of bottoming ORC cycle, and the separation pressure of topping flash cycle and the ammonia high pressure and the ammonia mixture strength are optimized. And the comparison of technical feasibility of different scenarios is given last.

All the thermodynamic calculations and optimizations are performed in the software of Engineering Equation Solver (EES) and Matlab programs.

3.3 Power Plant Scenarios

3.3.1 General Assumptions

1. Yangbajain geothermal field reservoir data was derived from the latest reservoir assessment report.
2. For this preliminary study, it is assumed that there is no non-condensable gas in the new design;
3. All heat transfer losses are neglected;
4. A shell and tube heat exchanger is applied as a condenser; A titanium plate heat exchanger is applied for the district heating supply system;
5. U (overall heat transfer coefficient) to calculate the area required for the heat exchanger was assumed :
   a) U = 0.9 for the evaporator
   b) U = 1 for the regenerator
   c) U = 1.5 for the condenser
   d) U = 1.5 for heat exchanger of district heating source
6. The efficiency of the pump and fan are 0.70, 0.60, respectively;
7. The efficiency of the turbine and generator is 0.85 and 0.95, respectively;
8. The temperature difference between cooling water entering the cooling tower and hot air leaving the cooling tower is 7 ºC;
9. The make up water of cooling tower is from the river nearby, the average temperature is 5 ºC;
10. A wet cooling tower is applied.
11. For district heating system design, snow melt water was the heating water source with inlet temperature of 5ºC and the outlet of 85 ºC.

3.3.2 Boundary Conditions

The boundary conditions are normally the hot end and cold end of a power plant. They are described detailed as follows:

(1) Hot end (i.e. geothermal fluid):

The Yangbajain field is the most important geothermal field in Tibet. The reservoir is divided into two sections, upper reservoir and lower reservoir. At present, only the upper reservoir has been utilized for power production. Figure 2 shows the elevation of the field and the location of the existing plants (Japanese International Cooperation Agency,2002, and Wang,Wei and Liu, 2006).

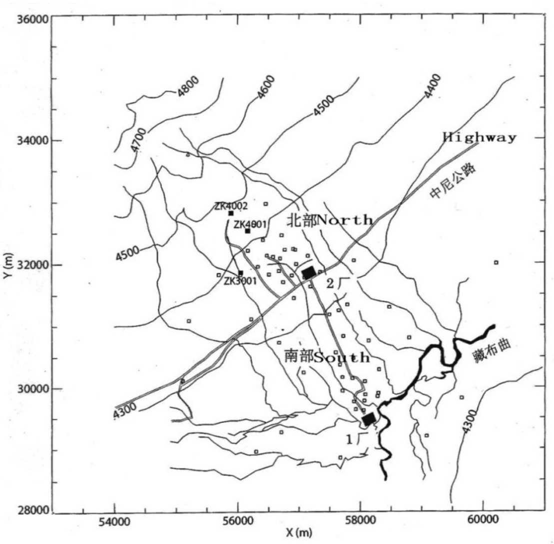

Figure 2: Yangbajain geothermal field and existing power plants location

According to the reservoir assessment report, the upper reservoir potential is assessed to be 167 t/h of steam production.

An exploration project of the lower geothermal resources was initiated in 1993. Two deep wells (ZK4001, ZK4002) have been drilled in northern area with a maximum down-hole temperature of 328.9ºC (ZK4002/1850m) and 252ºC (ZK4001/1450m). Additionally, there was another deep well drilled (ZK308) in the southern area with lower temperature, below 150 ºC. After that, a joint group of Chinese experts and members of the Japanese International Cooperation Agency carried out a lower geothermal reservoir assessment in 2006. It is this latest reservoir assessment report which was used at the main geothermal heat source reference for this study.

The research revealed that the lower geothermal resource with high enthalpy is distributed mostly in the northern area of Yangbajain field with temperatures of more than 200ºC. Then well testing and stimulation of well ZK4001 were successfully carried out. The main results are tabulated as follows:

Table 1. Well Testing Main Results of ZK4001.

Result item	Value
Wellhead Pressure (bar)	14.30
Mass flow rate (t/h)	280.90
Steam flow rate (t/h)	30.50
Water flow rate (t/h)	250.00
Enthalpy of the mass (kJ/kg)	1053.00

Then according to the reservoir modeling and simulation work (Japanese International Cooperation Agency, 2006), the final conclusions of the lower reservoir are given as follows:

1. The geothermal reservoir of Yangbajain has the ability to sustain the present production of the upper reservoir.

2. The total amount of steam production can be maintained at 200t/h in for the next 30 years including the upper and lower reservoir. It involves the existing upper wells and 3 more deep wells in total.

3. It is possible to produce the amount of 240t/h steam from the both upper and lower reservoir, but with associated risks.

(2) Cold end:

Yangbajain geothermal field is about 90km to the north of Lhasa with the altitude of 4300m, is 650m higher than Lhasa. The average outdoor dry bulb temperature is about 2.5 ºC. The average wet bulb temperature in Lhasa is -4.35 ºC. The average river temperature is about 5 ºC. The atmospheric pressure in Yangbajain field is 0.6bar. The average water temperature of the Zangbuqu River near the Yangbajain existing power plants is 5 ºC. It is an available cooling water resource for the new power plant as well.

3.3.3 Thermodynamic Calculations and Optimization of New Power Plant

According to the design concept, the different scenarios are performed in EES calculation procedure and Matlab programming.

3.3.3.1 Double Flash Cycle (Scenario 1)

Double flash cycle as the simplest and most common cycle is the first scenario to be considered for new design named as Scenario 1. The well data stated in the boundary conditions are used here for the present design. Therefore, one new deep well from the lower high enthalpy reservoir is the source of the first flash cycle. The enthalpy is 1053kJ/kg, and the mass flow is about 78kg/s. This high enthalpy geothermal fluid will go through the separator at the separation pressure P_1. Then the separated pure steam goes to the turbo-generator to generate electricity, while the separated brine goes to mix with the geothermal fluid from upper reservoir and after throttling valve to be lower pressure fluid for the second flash cycle. The temperature and mass flow of upper reservoir geothermal water is 145 ºC and 420kg/s, respectively. The second separation pressure is P_8 which together with P_1 are the main variables to optimize the net power output.

Determine the temperature of cooling water ($t_{c,in}$)

In Yangbajain geothermal field the highest ambient temperature all year round can reach around 25˚C with average relative humidity of air 54%. The highest wet bulb temperature is about 13˚C. The wet cooling tower is chosen for cooling condensed steam due to the high efficiency and available cooling water source. With a wet cooling tower the “cold water” temperature approaches the “wet bulb” temperature. In this study a “cold water” temperature of 7˚C is used for all the scenarios.

The pinch point between cooling water outlet and turbine exhaust temperature is the point to be determined in the design. The lower pinch could get higher power output, but the capital cost will be higher because of the bigger condenser area need. To keep the exit pressure at safe and manageable level, it is designed to be around 0.08bar, by assuming $T_{c,out}$ of 20˚C and then the pinch is 22˚C, the temperature of condensation would be 42˚C.

Optimization and analysis

The detailed calculations and optimization are performed in a double flash model set up in EES program and Matlab, the schematic diagram is shown below in Figure 3.

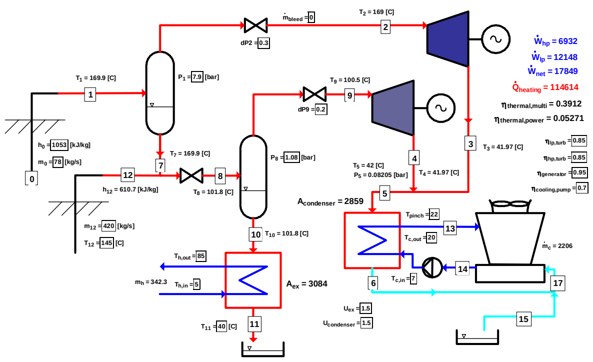

Figure 3: Schematic diagram of Scenario 1

The optimization work is to get the optimum separation pressures for each of the two separators which could maximize the net power output as well as the available discharge geothermal brine temperature for the district heating system. Therefore, the two separation pressure P_1 and P_8 are varied to seek the maximum net power output. It takes 208 runs in EES program to get the optimum results. By using Matlab program the optimum power output diagram is given as below with the optimum pressures: P_1=7.9bar; P_8=1.08bar. The maximum power is shown on the top central area to be 17,849kW.

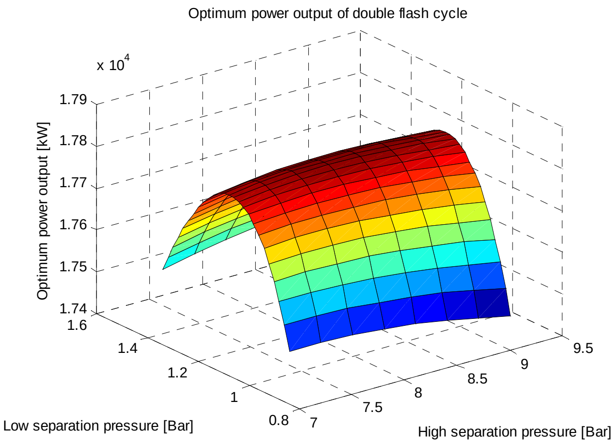

Figure 4: Optimum net power output of Scenario 1

On the other hand, the temperature of discharge of the geothermal brine for district heating system is variable according to the changing pressure. Table 2 shows the values around the optimum range which clearly indicates there’s definitely available hot water supply for the district heating system. Thus for the optimum system the supply temperature is 101.8°C.

Table 2. Temperature of Discharge Geothermal Brine Variation of Scenario 1.

High separation P_1 [bar]	Low separation P_8 [bar]	Net power output W_{net} [kW]	Temperature of discharge brine T_{10}[°C]	Heating capacity Q [kW]
7.3	1.06	17841	101.2	113510
7.6	1.07	17847	101.5	114064
7.9	1.08	17849	101.8	114614
8.2	1.09	17848	102.0	115161
8.5	1.10	17844	102.3	115704
8.8	1.11	17837	102.6	116243
9.1	1.12	17828	102.8	116779
9.4	1.13	17816	103.1	117311
9.7	1.14	17802	103.3	117840
10.0	1.15	17786	103.6	118366

The following figure shows the net power output contour corresponding to different separation pressures. The maximum output can be determined accurately and then the optimum pressures can be figured out. It is also indicated that the pressures of high and low separation process have a relatively big range resulting in the optimum power output. It means for practical operation of this system there are some flexible pressure choices which can also avoid some problems when the pressure drops or other emergency cases.

Main Results and discussion:

The main results of the double flash cycle design calculations are that the optimum net power output of this cycle is 17,849kW at separation pressures of 7.90bar and 1.08bar. The discharged geothermal brine which is still a high temperature is a good district heating source. The total capacity for district heating system is 114,614kW. Thus, it is known as a CHP plant giving higher utilizing efficiency of the geothermal resource. This is also a big benefit in solving the lack of heating systems in Lhasa.

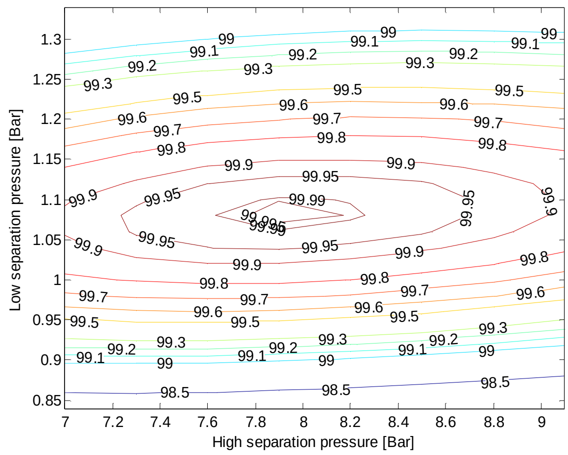

Figure 5: Net power output contour of Scenario 1

The maximum power output of double flash cycle is 17,849kW which is only 5.27% as the thermal efficiency of the system. However, as including the district heating capacity it supplies, the efficiency increases a lot up to 39.12%. There are only two heat exchangers are used as one condenser and one plate heat exchanger for heating system. According to the calculation, the total area of the heat exchangers is about 5943m^2.

3.3.3.2 Combined flash and ORC Cycle (Scenario 2)

The second scenario of the new design is a combined cycle plant with flash and ORC cycle called Scenario 2. This cycle is designed with the same assumptions and boundary conditions as Scenario 1. The design concept is to use high enthalpy geothermal reservoir in a topping flash cycle, and the separated brine combined with the low enthalpy from the upper geothermal reservoir will be used in bottoming ORC cycle. The working fluid is isopentane. The calculations and optimization analysis are performed as follows.

The detailed calculations and optimization are performed in EES program and Matlab, the schematic diagram is shown below in Figure 6. Similarly as designed in double flash cycle system, the geothermal fluid from the deep well extracting the high enthalpy geothermal resource goes into the topping flash cycle giving the power output W_{hp}. The separated brine together with the low enthalpy geothermal fluid goes to the heat exchanger of the ORC cycle which supplies the heat source of ORC bottoming cycle. The power output is denoted by W_{ORC}. The total shaft power is thus given as the work sum of these two cycles denoted by W_{shaft}. In addition, the auxiliary power input is from the cooling water circulating pump, ORC feed pump and the cooling tower fan. Therefore, the net power output W_{net} of the combined cycle can be given.

The optimization work is to input different values of the variables to work out which can result in the maximum power output. Here in this system, the high separation pressure P_9 for the topping flash cycle and the vaporizing pressure P_{vap} for the bottoming ORC cycle are the key input variables. In EES table calculation, the separation pressure P_9 and the vaporizing pressure P_{vap} are varied to calculate the net power output. It takes 221 runs to get the best results which show that the optimum pressures are: P_9=11.5bar; P_{vap}=6.5bar. Thus, the optimum results in Matlab are shown as follows. The carmine center area of the surf diagram indicates the maximum net power output as 25388kW in Figure 7. And the thermal efficiency for power output is 6.6%.

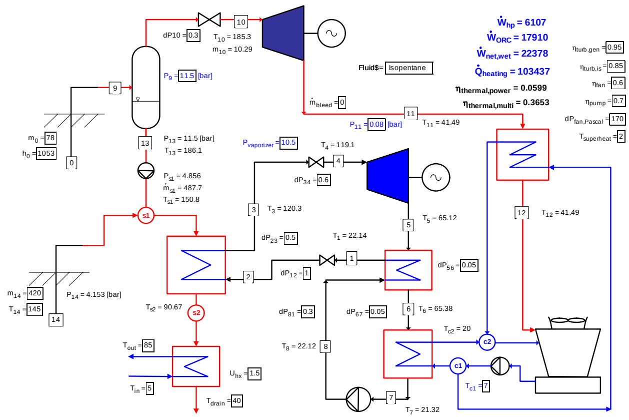

Figure 6: Schematic diagram of Scenario 2

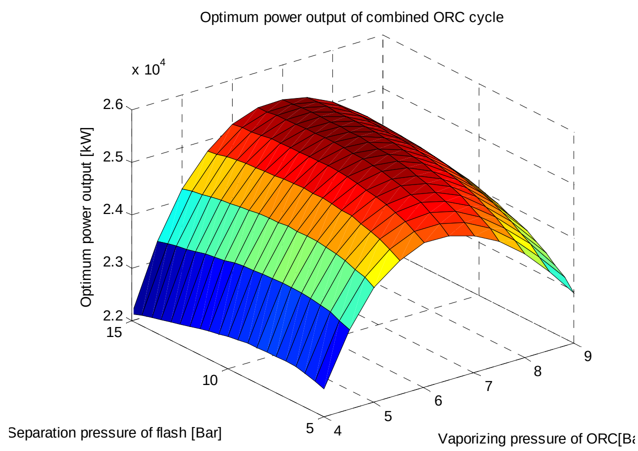

Figure 7: Optimum net power output of Scenario 2

In Figure 8 below, the net power output contour shows the maximum power output location and by which the optimum variables can be figured out. It also indicates that the separation pressure of topping flash cycle doesn't affect the final net power output too much. The more influencing factor is vaporizer pressure of ORC cycle.

This gives a good method to identify the maximum value as well as the tendency and accuracy of the value. It means for the practical operation of this system there are some flexible pressure choices as the same situation as Scenario 1.

Therefore, the topping cycle separation pressure is kept stable at the optimum value, the vaporizing pressure of bottoming ORC cycle is varied in order to identify the available discharge geothermal brine temperature. The following Table 3 indicates the variation of results with possible available temperatures for the district heating system. It will thus result in some decrease of optimum power output around 3MW. However, the huge district heating capacity deserves the sacrifice of power output depreciation.

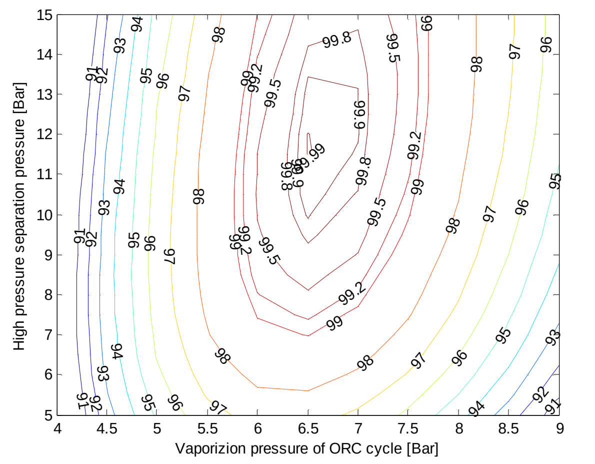

Figure 8: Net power output contour of Scenario 2

Table 3. Temperature of Discharge Geothermal Brine Variation of Scenario 2.

Separation pressure P9 [bar]	Vaporizer pressure Pvap [bar]	Net power output Wnet [kW]	Temperature of discharge brine T10[°C]
11.5	6.0	25283	59.69
11.5	6.5	25410	63.09
11.5	7.0	25381	66.49
11.5	7.5	25232	69.90
11.5	8.0	24965	73.32
11.5	8.5	24602	76.75
11.5	9.0	24156	80.20
11.5	9.5	23630	83.67
11.5	10.0	23036	87.16
11.5	10.5	22378	90.67
11.5	11.0	21664	94.20

By choosing the discharge temperature at 90.67°C, the corresponding pressures and power output are also obtained. The new vaporizing pressure is 10.5bar.

The optimum net power output of this cycle is 22378kW (i.e. about 22MW). The district heating system capacity is 103437kW. The thermal efficiency of pure power output is just 5.99%. By adding heating system capacity, it is increased considerably to 36.53%.

3.3.3.3 ORC Cycle Using Isobutane (Scenario 3)

Alternative Scenario 3 was designed also as a combined flash and ORC cycle but with isobutane as a working fluid in ORC cycle in the beginning. The process of calculation and optimization was quite similar as made for scenario 2. However, the optimization results showed that the higher pressures of both cycles, the more power output it can give. It is no more necessary to keep the topping flash cycle in this system. Therefore the new concept is to design an ORC cycle which makes use of combined geothermal brine from both upper and lower reservoir.

The schematic diagram is shown below in Figure 9. It is a binary cycle that s1 is the combination point of both reservoirs. The calculation assumptions are the same as the previous two scenarios. The shaft power is given as the work of ORC cycle using isobutane denoted by Wshaft. The auxiliary power input is from the cooling water circulating pump, ORC feed pump and the cooling tower fan. Therefore, the net power output W_{net} of the combined cycle can be given.

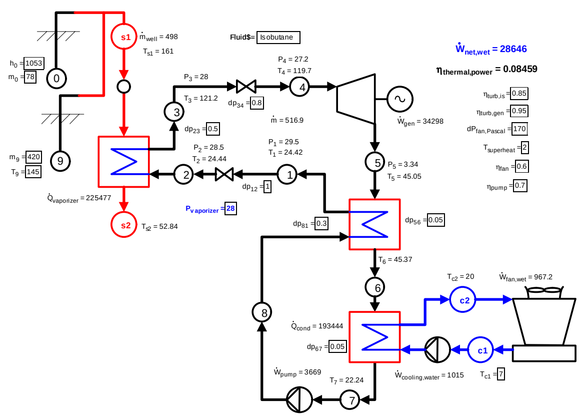

Figure 9: Schematic diagram of Scenario 3

The optimization work is to try different vaporizing pressure P_{vap} as input variable to find out the maximum power output. In EES table calculation, it is varied to calculate the net power output. The result shows that the higher P_{vap}, the more power output the cycle gives. Considering the critical point of isobutane is 36.4bar, to keep the cycle at safe working level, P_{vap} of **28bar** is chosen for the final optimum cycle. As indicated in Table 4 below, the temperature of discharge geothermal brine is kept always low. Therefore, there's no possibility for district heating supply.

Table 4. Optimization calculation of Scenario 3.

Vaporizer pressure P_{vap} [bar]	Net power output W_{net} [kW]	Temperature of discharge brine T_{s2}[°C]
21	27458	46.13
22	27704	47.35
23	27907	48.52
24	28081	49.61
25	28232	50.61
26	28366	51.51
27	28495	52.28
28	28646	52.84
29	28820	53.2
30	29264	53.18

3.3.3.4 Combined flash and Kalina cycle (Scenario 4)

The fourth scenario of the new design is the combined cycle with flash and Kalina cycle called Scenario 4. This cycle is designed with the same assumptions and boundary conditions as the former scenarios.

The detailed calculations and optimization are performed in EES program and Matlab, the schematic diagram is shown below in Figure 10. In a similar design concept as the former scenarios, the high enthalpy reservoir is utilized in the topping flash cycle which enters the cycle at separation pressure P_{12}, and the power output is W_{hp}. The bottoming one is Kalina cycle using the separated brine from the first separator mixed with the low enthalpy reservoir as the heat source of the cycle. Thus, the supply heat source is at the temperature of $T_{source,in}$ and the mass flow rate of m_{source}. The significant factors of the Kalina cycle are the high pressure

$P_{high,1}$ of the ammonia mixture working fluid and the ammonia mixture strength x_m. The power output of the Kalina cycle is denoted by W_{kalina}. Thus the total shaft power output W_{shaft} is given as the sum of these two. Additionally, the auxiliary power inputs are due to the cooling water circulating pump, Kalina feed pump and cooling tower fan. The net power output of this combined flash and Kalina cycle is finally calculated as W_{net}.

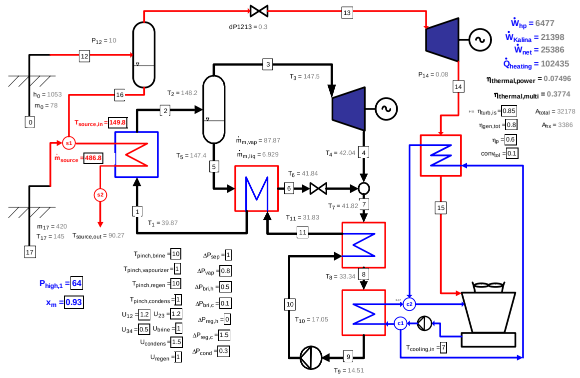

Figure 10: Schematic diagram of Scenario 4

The optimization work for this combined flash and Kalina cycle is more complicated than the former work since there are three variables to determine. They are the separation pressure P_{12} of the topping flash cycle, the high inlet pressure $P_{high,1}$ for the ammonia mixture and the ammonia mixture strength x_m of the bottoming Kalina cycle. The method applied here is to make a calculation first for the topping flash cycle to give some variables of separation pressure P_{12}. By using different P_{12} and relative values as input parameters to the bottoming Kalina cycle, then vary the other two variables so as to optimize the entire system. After a lot of trials, it gives the maximum power output of **28251 kW** at the input condition as follows: P_{12}=10 bar, $P_{high,1}$=41 bar, x_m=0.93. Thus, the surf diagram is performed in Matlab shown below:

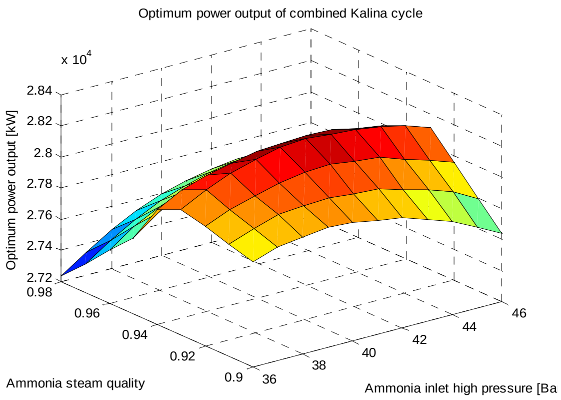

Figure 11: The optimum net power output of Scenario 4

The net power output contour of Scenario 4 indicates that the ammonia mixture strength has more influence to the power output than the ammonia high inlet pressure $P_{high,1}$. The net power output can be kept over 99% of the maximum value in the range of 36 to 46 of $P_{high,1}$. While by varying ammonia mixture strength, the power output can be decreased more as shown in the contour diagram of Figure 12 below.

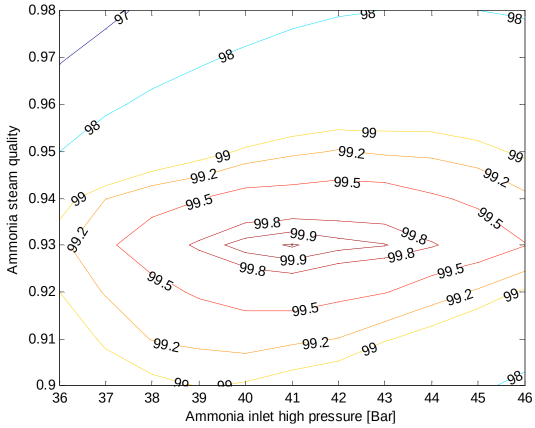

Figure 12: Net power output contour of Scenario 4

The following figures indicate the relationships between three variables and net power output. The relationships between net power output and P_{12}, x_m, and $P_{hgih,1}$ respectively are showing the peak points which could result in the optimum value.

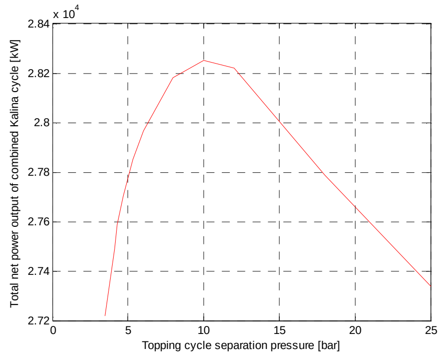

Figure 13: W_{net} as a function of topping cycle separation pressure P_{12}

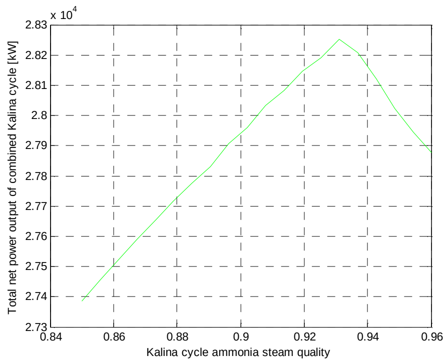

Figure 14: W_{net} as a function of bottoming Kalina cycle ammonia steam quality x_m

In order to obtain the available temperature of discharge geothermal brine $T_{source,out}$, calculations of three input variables have been carried out. The results show that the most sensitive input variable is the high inlet pressure of ammonia mixture $P_{high,1}$. Therefore, Table 5 indicates the results of varied calculation by changing $P_{high,1}$. Considering the feasibility of district heating system, $T_{source,out}$ =90.27 is selected. Thus, the final optimum system is determined at the condition of: P_{12}=10 bar, $P_{high,1}$ =64bar, x_m =0.93.

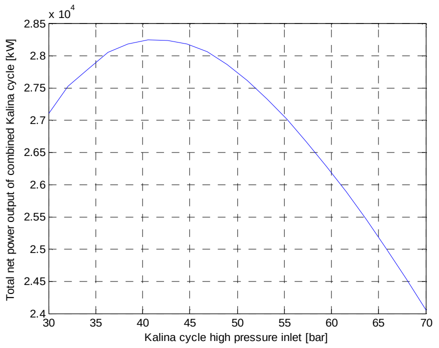

Figure 15: W_{net} as a function of Kalina cycle ammonia high pressure $P_{high,1}$

Table 5. Temperature of Discharge Geothermal Brine Variation of Scenario 4.

P_{12} [bar]	$P_{high,1}$ [bar]	x_m	W_{net} [kW]	$T_{source,out}$[°C]
10	40	0.93	28237	77.39
10	43	0.93	28224	79.50
10	46	0.93	28113	81.31
10	49	0.93	27855	82.79
10	52	0.93	27489	84.24
10	55	0.93	27060	85.69
10	58	0.93	26547	87.17
10	61	0.93	25999	88.66
10	64	0.93	25386	90.27
10	67	0.93	24744	91.91

The optimum net power output of this cycle is 25386kW. The district heating system supply capacity is 102435kW.

3.3.4 Analysis and Comparison of All Scenarios

The calculations and optimization work for different alternative scenarios have been carried out in the last section. The main results of each scenario are summarized as in Table 6:

Table 6. Summary of Optimum Results of Each Scenario.

Item	Scenario 1	Scenario 2	Scenario 3	Scenario 4
W_{net} (kW)	17,849.0	22,378.0	28,646.0	25,386.0
$Q_{heating}$ (kW)	114,614.0	103,437	0	102,435.0
$T_{source,out}$ (ºC)	100.70	90.67	52.84	90.27
A_{total} (m^2)	5,943.0	22,257.0	39091.0	32722.3
$\eta_{thermal,power}$ (%)	5.27	5.99	8.46	7.50
$\eta_{thermal,multi}$ (%)	39.12	36.53	-	37.74

It is clear that the Scenario 1 of double flash cycle produces the lowest net power output but highest district heating capacity in contrast with the other scenarios. The highest net power output is from Scenario 3 which is pure ORC cycle with isobutane as the working fluid. But there is no district heating capacity supply in this system. The Scenario 2 is a hybrid flash and ORC cycle with isopentane working fluid. The maximum power output without heating supply of this system is 25,388kW, and after optimization, the optimum power output is 22,378 with good heating capacity of 103,437kW. Then the final scenario named Scenario 4 is designed as a combined flash and Kalina cycle. Similarly as in Scenario 2, the maximum power output is 28,251KW without heating capacity. Then the optimum system can produce 25,386kW electricity and 102,435kW heating power. Thus, both for Scenario 2 and Scenario 4, by sacrifice around 3MW power output, they can supply around 100MW heating capacity. The thermal efficiency of the power plant can increase considerably.

It is also obvious to see that Scenario 3 gives the highest pure power efficiency of 8.46% but without heating capacity. It is also clear that Scenario 1 gives the highest multiple thermal efficiency including power and heating. Therefore, they are all feasible at technical point of view. Since each scenario has its benefit, how to determine the optimum design is also dependent on the economic analysis which also should take into account the district heating system evaluation. A design system analysis of district heating system is thus performed in next section. The overall economic feasibility study will be carried out in Chapter 4.

3.4 Technical Feasibility Study of District Heating System Proposal

As designed in the power generation section, the available heating capacity which can be supplied by three scenarios is roughly about 100-110MW, with supply temperature of 85 ºC. A cold water source from melted snow is used to be heated-up by discharge geothermal brine of the CHP plant which is also named as regeneration power plant. The mass flow of heated water is about 308.9 kg/s, 326.3 kg/s, and 342.3kg/s from different power cycle scenarios. The long distance district heating system design schematic system diagram is shown in Figure 16 below:

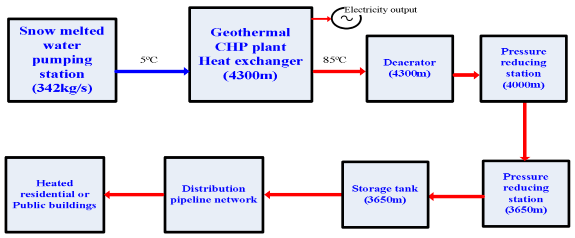

Figure 16: Schematic diagram of geothermal district heating system from CHP plant

The cold water transmitted in the district heating system is from snow melted in a water tank which is built adjacent to power plant. The heat source is from the power plant's discharged geothermal brine. The heat exchanger applied in the system is a titanium plate heat exchanger due to the chemical features of the geothermal brine. The snow melt water will be heated from 5 ºC to 85 ºC and then will be transmitted by pipeline to a storage tank which is built close to Lhasa city. From Yangbajain geothermal power plant to the storage tank, the distance is roughly measured to be 90050m. The elevation decreases 600m from 4300m to 3650m. The big elevation difference results in the high pressure difference along the piping route. Therefore the design will construct two pressure reducing stations to reduce transmission high pressure. The hot water from heat exchanger first goes to deaerator to get deaerated for preventing corrosion during transmission. Then it goes along the long distance pipeline to the storage tank before distributed to the heat consumers.(Karlsson, 1982).

3.4.1 Transmission Pipeline Route Design

According to the conceptual design of this long distance district heating system, the transmission pipeline starts from Yangbajain CHP plant at the elevation of 4300m. Heated water will go through the pipe by gravity without any pumping cost to Lhasa city which is at 3650m elevation. The pipeline is designed to be mostly underground laid along the railway and the highway route while some certain parts will be laid over ground if underground laying is not possible. It is mostly river bed landscape rather than the hard rock or frozen earth, thus it is technically feasible. The pipeline is pre-insulated steel pipe. The rough pipeline route is shown in Figure 17.

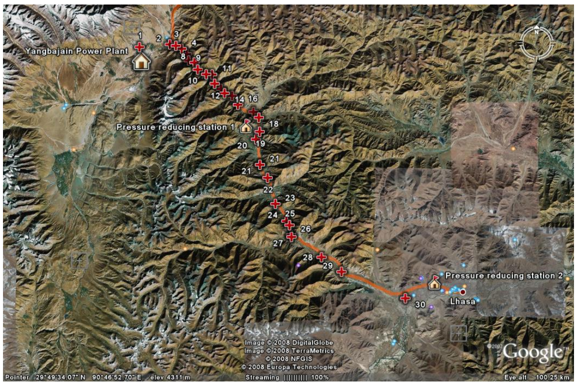

Figure 17: Proposed transmission route from Yangbajain CHP plant to Lhasa

The profile of this proposed pipeline is given in Figure 18. By figuring out 30 points for designed the transmission route in Google earth, each point's altitude can be found. The profile from Lhasa to Yangbajain is approximately linear. Therefore, the calculations and analysis of pressure and temperature drop of the pipeline is carried out based on this profile in this preliminary study. (Valdimarsson,1993).

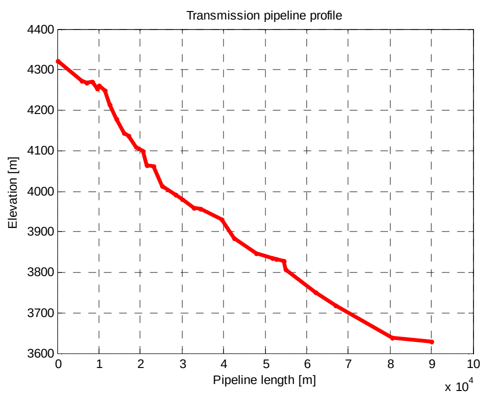

Figure 18: Transmission pipeline profile

<u>3.4.2 Transmission Pipeline Calculation</u>

(1) Pressure loss

The water flow pressure loss in pipelines is composed of elevation changes and wall friction two parts. The pressure along the pipeline can be calculated by the equation below(Valdimarsson,1993):

$$P_B = P_A - \rho g \cdot (\Delta Z_{B-A} + f \cdot \frac{L}{D} \cdot \frac{v^2}{2g}) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

Where, P_B= Pressure of pipeline outlet, Pa;

P_A= Pressure of pipeline inlet, Pa;

ΔZ_{B-A}= the change in pipe elevation from A to B, ZB-ZA, m;

f = Friction factor, based on the pipe roughness, pipe diameter, and the Reynolds number, can be obtained from engineering handbooks.2,3 For most applications, the value of this friction factor will be between 0.015 and 0.0225. Here it is 0.016 which is calculated in EES;

v = Average flow velocity in m/s;

L= Pipe length in meters;

D= Pipe inner diameter in meters;

ρ= Heated water density in m3/kg.

g = Gravity acceleration constant.

The pipeline model is set up in EES program which is based on the proposed transmission route profile. The pressure loss calculation in gravity head curve is shown in Figure 53. The diameter for this pipeline is DN500, 508/630, and the thickness is 8.8mm. It can sustain the highest pressure of 40bar. The elevation changes are shown by the black dashed line, while the other curves indicate the pressure loss at different water flow rates. The red one represents the design water flow rate of 342.3kg/s which can keep in good transmission condition at initial pressure. From the other results at lower flow rate of 300kg/s and 250kg/s, it is clear that if there's less flow rate in the pipeline, the pressure also reduce less. To keep the transmission pipeline at safe level, the pressure reducing stations are required along the pipeline.

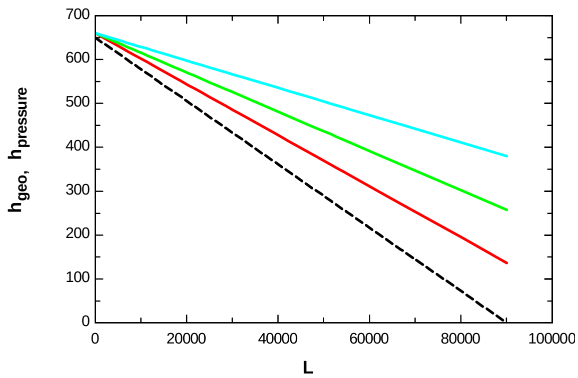

Figure 19: Transmission gravity head drop in pipeline

(2) Temperature loss

The temperature loss during transmission can be calculated as below:

$$T_2 = T_{outdoor} + (T_1 - T_{outdoor}) \cdot e^{(-\frac{k \cdot L}{\dot{m} \cdot C_p})} \qquad (2)$$

Where, T_2 = transmission pipeline outtake temperature (i.e. distribution supply temperature), ºC;

$T_{outdoor}$= outdoor temperature during pipeline working time, ºC;

T_1 = intake temperature of transmission pipeline from power plant, ºC;

k = coefficient of heat transfer from center of pipe to ambient air, in this case for DN500, 508/630 pipeline, is 0.8W/m. ºC (Peter Randlov, 1997);

L = transmission pipeline length, m;

m = transmission water mass flow rate, kg/s;

C_p = specific heat capacity, kJ/kg. ºC, for water, it is 4187kJ/kg. ºC.

It is also calculated based on the designed pipeline route shown in Figure 20. The length is 90050m from Yangbajain power plant to the storage tank. Therefore, the temperature at outlet of pipeline is 80.2 ºC.

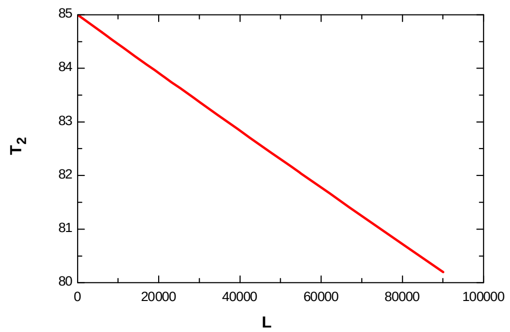

Figure 20: Temperature drop in the pipeline

4. ECONOMIC FEASIBILITY STUDY OF YANGBAJAIN GEOTHERMAL POTENTIAL

The aim of carrying out an economic feasibility study of different scenarios is to determine which scenario is the most financially viable. Every project is implemented with the same objective of getting positive returns from investment in the view of business investment. Financial viability analysis is significant factor to determine which alternative is finally selected. Engineering economic study is introduced to make this feasibility study. Some definition and principles are applied for all alternatives stated in the previous chapters including the power generation alternatives and the long distance district heating system.(Leland and Anthony,2002).

4.1 Cost Estimation and Cash Flow of Proposed Power Plant Scenarios

There are four different proposed power plant scenarios designed in Chapter 3. The economic evaluation is performed here by using the present value methodology and process. First of all, the cost estimation is made for each alternative including investment, operation and income cost. Then the evaluation analysis is performed based on the cash flow in their proposed life span. For all the alternatives, the drilling and related cost of all re-injection wells is included for sustainable development concerns.

4.1.1 The CHP Plant Using Double Flash Cycle (Scenario 1)

The first scenario designed is a CHP plant using double flash cycle. The main components of this plant are two turbo-generators, one condenser, cooling circulating pump, the cooling tower, and etc as shown in the schematic diagram in Figure 3 of Chapter 3. The cost estimates are listed in the table 7.

According to the cost estimation, the cash flow series can be made in the life span of the proposed project. The total investment cost is $21,733,000 at the beginning, and after 10 years, there will be another well drilled for ensuring the production at the cost of $1,375,000. The annual revenue after-tax is $8,483,000, and the annual expense is $1,507,000 as shown below in Figure 21.

Table 7. Summary of Cost Estimation for Scenario 1.

Cost estimates	Cost (USD)
1. Fixed capital investment	**19,580,000**
A. Purchased Equipment Cost (PEC)	8,612,000
Steam turbo-Generator (HP)	2,260,000
Steam turbo-Generator (LP)	3,960,000
Cooling water circulation pump	270,000
Condenser	801,000
Wet cooling tower	1,321,000
B: Drilling and installation costs	10,968,000
Cost of drilling a deep wells and instruments (2500m x US$550/m) another one will be drilled 10 years later	1,375,000
Reinjection well drilling and instruments cost	3,025,000
Pumping and connection of the reinjection wells (20% of drilling cost)	454,000
Piping, valves and fittings (25% of PEC)	2,153,000
Instrumentation and control (45% of PEC)	3,875,000
Shipping (1% of PEC)	86,000
2. Construction related costs	**2,153,000**
Design and consultancy (5% of PEC)	431,000
Construction Cost (20% of PEC)	1,722,000
Commissioning and startup (3% of PEC)	258,000
TOTAL CAPITAL INVESTMENT	21,733,000
3. Annual O&M Costs	**1,076,000**
Labor cost(10 persons, 3000yuan/month)	51,000
Maintenance costs (1% of investment)	217,000
Operating cost (1% of investment)	217,000
Auxiliary electricity costs	591,000
4. Annual capital cost	**1,518,000**
Annual depreciation costs (Economic life span of 20 years)	1,087,000
Interest rate (5%)	431,000
Total annual cost	**2,594,000**
TOTAL ANNUAL EXPENSE(Cash payment)	**1,507,000**
ANNUAL INCOME (Electricity sales at 0.41yuan/kWh)	**8,782,000**
Annual tax payment (3.4% of total income)	**299,000**
ANNUAL REVENUE (Annual income - Tax)	**8,483,000**
Annual profit (Annual revenue-annual expense)	**5,889,000**
Recovery year	**3.69**

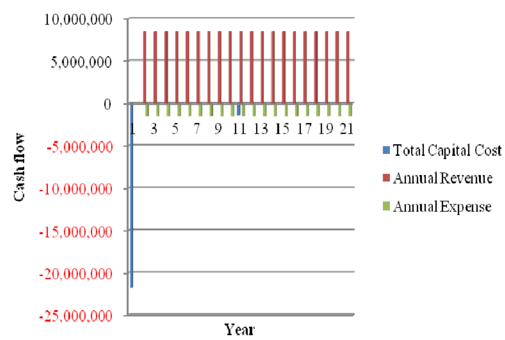

Figure 21: Cash flow of double flash power plant scenario 1

4.1.2 Combined Flash and ORC Cycle Using Isopentane (Scenario 2)

The second scenario designed as a combined flash and ORC cycle with isopentane as the working fluid for bottoming ORC cycle. According to the thermodynamic calculation and optimization, it is feasible to supply the district heating for this system. The main components of this plant are two turbine-generators, one vaporizer, two condensers, and etc, as shown in the schematic diagram in Figure 6 of Chapter 3. The cost estimates are listed in the following table.

Table 8: Summary of economic analysis for Scenario 2.

Cost estimates	Cost (USD)
1. Fixed capital investment	**32,444,000**
A. Purchased Equipment Cost (PEC)	**16,046,000**
Steam turbo- Generator (HP)	1,991,000
Organic turbo- Generator (ORC)	7,164,000
ORC Feed Pump	51,000
Cooling water circulation pump	269,000
Evaporator	2,375,000
Condenser (HP)	139,000
Condenser (ORC)	2,681,000
Wet cooling tower	1,376,000
B: Drilling and installation costs	**16,398,000**
Cost of drilling a deep wells and instruments (2500m x US$500/m for each) another well drilled 10 years later	1,375,000
Reinjection well drilling and instruments cost	3,025,000
Pumping and connection of the reinjection wells (20% of drilling cost)	605,000
Piping, valves and fittings (25% of PEC)	4,012,000
Instrumentation and control (45% of PEC)	7,221,000
Shipping (1% of PEC)	160,000
2. Construction related costs	**4,011,000**
Design and consultancy (5% of PEC)	**802,000**
Construction Cost (20% of PEC)	**3,209,000**
Commissioning and startup (3% of PEC)	**481,000**
TOTAL CAPITAL INVESTMENT	**36,455,000**
3. Annual O&M Costs	1,568,000
Labor cost(10 persons, 3000yuan/month)	51,000
Maintenance costs (1% of investment)	365,000
Operation costs(1% of investment)	365,000
Auxiliary electricity costs	787,000
4. Annual capital cost	2,625,000
Annual depreciation costs (Economic life span of 20 years)	1,823,000
Interest rate (5%)	802,000
Total annual cost	**4,193,000**
TOTAL ANNUAL EXPENSE(Cash payment)	**2,370,000**
ANNUAL INCOME (Electricity sales at 0.4yuan/kWh)	**11,010,000**
Annual tax payment (3.4% of income)	**374,000**
ANNUAL REVENUE (Annual income - Annual Tax)	**10,636,000**
Annual profit (Annual revenue- Annual expense)	**8,266,000**
Recovery year	**4.41**

According to the cost estimation, the cash flow chart can be made for the life span of the proposed project. Figure 22 below shows the cash flow during 20 a year lifetime.

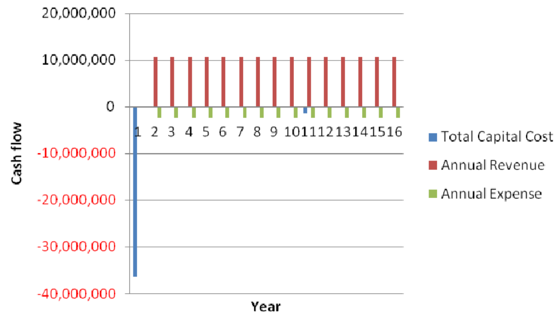

Figure 22: Cash flow of double flash power plant Scenario 2

4.1.3 ORC Cycle Using Isobutane (Scenario 3)

The third scenario is designed as a pure ORC cycle with isobutane as the working fluid. According to the thermodynamic calculation and optimization, there's no district heating capacity for this system. The main components of this plant are a single turbo-generator, vaporizer, condenser, cooling tower, and etc as shown in the schematic diagram in Figure 9 of Chapter 3. The cost estimates are listed in the table 9 and the cash flow chart is shown in Figure 23.

4.1.4 The CHP Plant Using Hybrid Flash and Kalina Cycle (Scenario 4)

The last scenario designed as a hybrid flash and Kalina cycle. According to the thermodynamic calculation and optimization, it is also feasible to supply the heating capacity for district heating system. The main components of this plant are two turbo-generators, one vaporizer, two condensers, the cooling tower, and etc, as shown in the schematic diagram in Figure 19 of Chapter 4. The cost estimates are listed in the table 10.

4.2 Evaluation of all Alternative Scenarios Using PW Value Method

Based on the cash flow series of each alternative, the IRR evaluation can be carried out. Figure 25 shows the curves of NPV value as a function of rate in the expected life span for all alternatives. It indicates the IRR results of all four alternative scenarios when NPV is equalized to zero. It is obvious that Scenario 1 designed as double flash cycle power system has the highest IRR as 31.84%, followed by Scenario 2 as 22.15%, Scenario 4 as 14.86% and the last one Scenario 3 as 9.57%.

In a summary of cash flow series and IRR value for each alternative are shown in Table 11. The lowest total investment is from Scenario 1 and the highest revenue is from Scenario 2. The worst scenario is Scenario 3 since the IRR is the lowest and additionally it does not have district heating supply capacity.

Table 9. Summary of Economic Analysis for Scenario 3.

Cost estimates	Cost (USD)
1. Fixed capital investment	**51,667,000**
A. Purchased Equipment Cost (PEC)	**27,642,000**
Organic vapor turbo- Generator (ORC)	13,719,000
ORC Feed Pump	84,000
Cooling water circulation pump	329,000
Evaporator (ORC)	6,369,000
Condenser (ORC)	5,013,000
Wet cooling tower	2,128,000
B: Drilling and installation costs	**24,025,000**
Cost of drilling a deep wells and instruments (2500m x US$550/m for each) another well drilled 10 years later	1,375,000
Reinjection well drilling and instruments cost	3,025,000
Pumping and connection of the wells (20% of drilling cost)	275,000
Piping, valves and fittings (25% of PEC)	6,911,000
Instrumentation and control (45% of PEC)	12,438,900
Shippping (1% of PEC)	276,000
2. Construction related costs	**8,292,000**
Design and consultancy (10 % of PEC)	**2,764,000**
Construction Cost (20% of PEC)	**5,528,000**
Commissioning and startup (3% of PEC)	**829,000**
TOTAL CAPITAL INVESTMENT	**59,959,000**
3. Annual O&M Costs	5,331,000
Labor cost(10 persons, 3000yuan/month)	62,000
Maintenance costs (1% of investment)	600,000
Operation costs (1% of investment)	600,000
Auxiliary electricity costs	4,069,000
4. Annual capital cost	**4,380,000**
Annual depreciation costs (economic life span of 20 years)	2,998,000
Interest rate (5%)	1,382,100
Total annual cost	**9,711,000**
TOTAL ANNUAL EXPENSE(Cash payment)	**6,713,000**
ANNUAL INCOME (Electricity sales at 0.41yuan/kWh)	**14,094,000**
Annual tax payment (3.4% of income)	**479,000**
ANNUAL REVENUE (Annual income - Annual Tax)	**13,615,000**
Annual profit (Annual revenue-Annual expense)	**6,902,000**
Recovery year	**8.69**

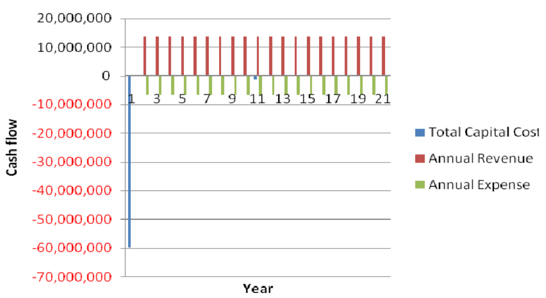

Figure 23: Cash flow of ORC power plant Scenario 3

Table 10. Summary of economic analysis for Scenario 4.

Cost estimates	Cost (USD)
1. Fixed capital investment	**41,604,000**
A. Purchased Equipment Cost (PEC)	**21,723,000**
Steam turbo- Generator (HP)	2,112,000
Ammonia vapor turbo- Generator (Kalina)	8,559,000
Feed Pump	26,000
Cooling water circulation pump	239,000
Evaporator	4,177,000
Regenerator	143,000
Brine heat exchanger	25,000
Condenser (HP)	152,000
Condenser (Kalina)	4,944,000
Wet cooling tower	1,346,000
B: Drilling and installation costs	**19,881,000**
Cost of drilling two deep wells and instruments (2500m x US$500/m for each) another well drilled 10 years later	1,375,000
Reinjection well drilling and instruments cost	3,025,000
Pumping and connection of the wells (20% of drilling cost)	275,000
Piping, valves and fittings (25% of PEC)	5,431,000
Instrumentation and control (45% of PEC)	9,775,000
Shipping (1% of investment)	217,000
2. Construction related costs	**6,517,000**
Design and consultancy (10 % of PEC)	2,172,000
Construction Cost (20% of PEC)	4,345,000
Commissioning and startup (3% of PEC)	652,000
TOTAL CAPITAL INVESTMENT	**48,121,000**
3. Annual O&M Costs	2,208,000
Labor cost(10 persons, 3000yuan/month)	51,000
Maintenance costs (1% of investment)	481,000
Operation cost (1% of investment)	481,000
Auxiliary electricity costs	1,195,000
4. Annual capital cost	4,578,000
Annual depreciation costs (Economic life span of 20 years)	2,406,000
Interest rate (5%)	2,172,000
Total annual cost	**6,786,000**
TOTAL ANNUAL EXPENSE(Cash payment)	**4,380,000**
ANNUAL INCOME (Electricity sales at 0.4yuan/kWh)	**12,490,000**
Annual tax payment (3.4% of total income)	**425,000**
ANNUAL REVENUE (Annual income - Annual Tax)	**12,065,000**
Annual profit (Annual revenue-Annual expense)	**7,685,000**
Recovery year	**6.26**

According to the cost estimation, the cash flow chart can be made for the life span of the proposed project. Figure 24 below shows the cash flow during the 20 year lifetime.

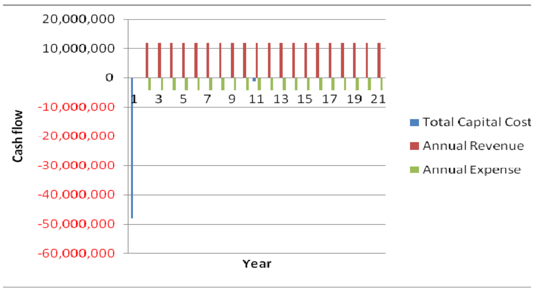

Figure 24: Cash flow of hybrid flash and Kalina cycle Scenario 4

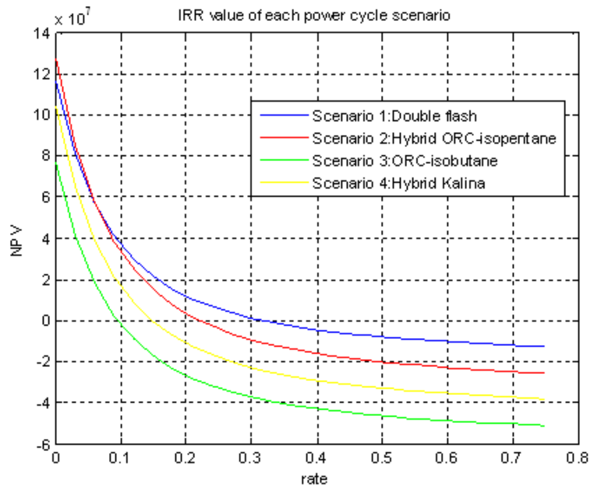

Figure 25: NPV as a function of rate of return of each scenario

Table 11. Summary of Cash Flow Series and Main Profitability Results.

Item	Cash flow (US$)			
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
PV(0)	-21,733,000	-36,455,000	-59,959,000	-48,121,000
PMT(1-9)	6,976,000	8,266,000	6,902,000	7,685,000
PMT(10)	5,601,000	6,891,000	5,527,000	6,310,000
PMT(11-20)	6,976,000	8,266,000	6,902,000	7,685,000
FV	116,412,000	127,490,000	76,706,000	104,204,000
IRR	31.84%	22.15%	9.57%	14.86%

In incremental IRR principle, Scenario 1 and Scenario 2 are taken into the comparison assessment to figure out which one is more financially viable. The cash flow subtraction of two alternatives is performed to calculate the new IRR in Figure 26.

The new IRR is calculated to be 6.06% which is much lower than the one Scenario 1 gives. In the same principle, Scenario 4 is definitely not as profitable as Scenario 1. Therefore, for only considering power generation economical viability, the Scenario 1 is the most economically feasible with the highest IRR value of 31.84%.

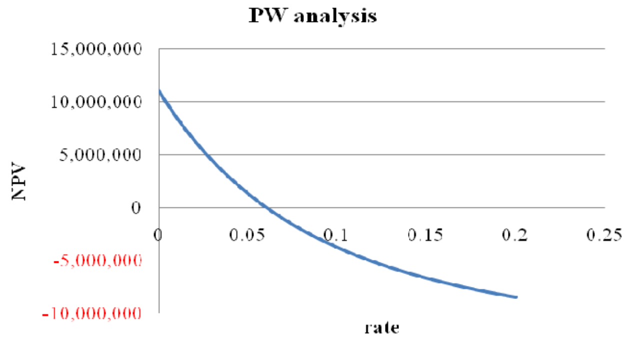

Figure 26: NPV as a function of rate of return in Incremental IRR analysis

4.3 District Heating System Economic Analysis

In a district heating system, the annual cost includes the annual investment cost and annual O&M cost, the main annual cost factors conclude: (Valdimarsson,1993)

- Capital costs
- Pumping costs
- Maintenance
- Heat and water loss in the distribution system

For a geothermal district heating system, the capital cost includes the investment cost of all the components which can be divided into three main parts:

- Supply system (well drilling and maintenance, pumps and accessories, or cogeneration power plant heat exchangers, etc)
- Distribution pipe network (construction the pipeline, pipes, connections, etc)
- Building system (radiator, pipes, control valves and accessories)

The annual O&M cost includes the pumping cost, maintenance (labor cost and repair) as well as heat and water loss in the distribution system. The labor cost is quite low in China, the repair work and heat water loss will not account a big proportion. The most costly part is the pumping cost in most cases. However, in this long distance geothermal district heating system, due to the big elevation difference from Yangbajain to Lhasa, there's no pumping cost. Instead, the pressure reducing stations are necessary.

4.3.1 Cost Estimation

According to the pipeline calculation results, the appropriate diameter of pipeline is DN500, and the outer diameter and casing is 508/630mm. The pipe is selected as the pre-insulated standard steel pipe. The design maximum flow rate is 342kg/s, and the pipeline estimated length is 90050m. The estimated investment cost and annual cost are tabulated below. The life span of this geothermal district heating system is 20 years as well.

In annual income estimates, as a new and first district heating system built in Lhasa, there's no ready standard to refer to. According to the local energy supply condition, comparing with other heating facilities in Tibet, using electricity heating the fee is about 55yuan/m2, using diesel for heating it can be around 90yuan/m2. Solar heating is more suitable for small households or remote area. The geothermal heating charge system is recommended to be differentially charged according to the function of building. It can be charged based on the heated area, therein for residential building it is 40yuan/m2 and for public building it is 50yuan/m2 (with no more than 3.5m height for each floor) as recommendation.

The estimates of total capital investment, the annual total cost, as well as annual total income are shown in Table 37 above.

It is apparent that for this long distance district heating system, the investment cost is very high due to the long transmission pipeline construction. Even without pumping cost in the annual cost, the recovery period is quite long. The detailed profitability evaluation is carried out in following section.

Table 12. Summary of Economic Analysis for Scenario 4.

Cost estimates	Cost (USD)
1. Transmission capital investment	**70,201,000**
A. Purchased equipment cost (PEC)	**39,378,000**
Titanium heat exchanger	1,630,000
Pre-insulated Steel pipeline purchase cost (DN500, 90050m)	38,451,000
Pressure reducing valves(2 Sets)	350,000
Water source filter, deaerator and instruments	505,000
Electric control system	72,000
B. Installation cost	**15,072,000**
Total earth work and manual work of transmission pipeline	14,678,000
Installation all stations equipments	394,000
C. Construction related costs	15,751,000
Design and consultancy (5% of PEC)	1,969,000
Construction Cost (Cold water station, pressure reducing stations, 30% of PEC)	13,782,000
2. Distribution network capital investment (1.6million area)	**8,800,000**
3. Building system capital investment	**32,000,000**
TOTAL CAPITAL INVESTMENT	**111,001,000**
4. Annual O&M Costs	**87,000**
Labor cost (12persons, 3000yuan/month)	**62,000**
Pumping cold water cost	**10,000**
Maintenance costs	**15,000**
5. Annual capital cost	**3,938,000**
Annual depreciation costs (Economic life span of 20 years)	1,969,000
Interest rate (5% of PEC)	1,969,000
Total annual cost	**4,025,000**
TOTAL ANNUAL EXPENSE	**2,056,000**
ANNUAL INCOME	9,943,000
Heating fee	9,714,000
Connection fee	229,000
Annual tax payment (3.4%)	338,000
ANNUAL Revenue (Annual income - Annual tax)	9,605,000
Annual profit (Annual revenue - Annual expense)	7,549,000
Recovery year	14.70

4.3.2 PW Value Profitability Evaluation

Based on the system cost estimation, a cash flow series is also performed as in Figure 27 for 20 years life span.

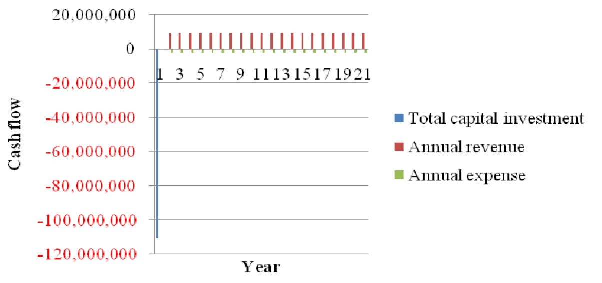

Figure 27: Cash flow series of district heating system

The IRR calculation illustrates that the IRR equals to 3.13%. It reveals building this long distance district heating system is not very profitable.

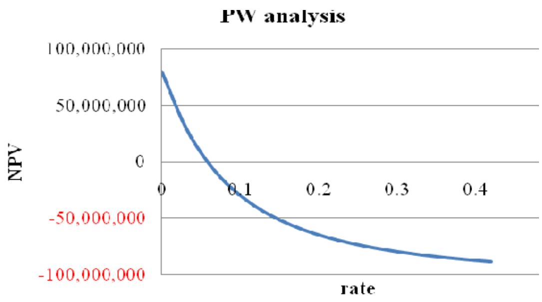

Figure 28: NPV as a function of rate of return of district heating system

4.6 CHP Power Plant Combined Economic Analysis

As assessed in power cycle scenarios section, the most economic feasible alternative is Scenario 1 designed as double flash cycle. In the view as an entire CHP power plant with the combination of power cycle and district heating system, By combining district heating system with the most profitable double flash cycle, it yields integrally positive profitability. The evaluation is shown below:

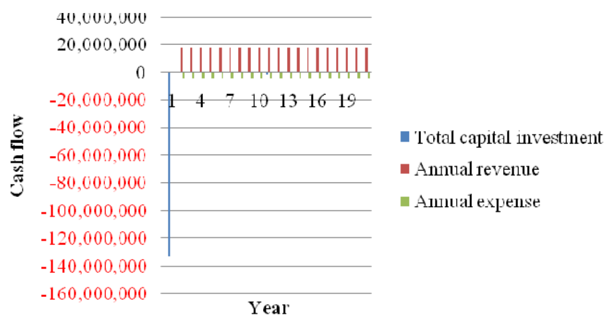

Figure 29: Cash flow of double flash CHP power plant

Therefore, the final IRR can be 8.92%. This evaluation is based on the pure commercial business consideration. It shows that only constructing power plant the IRR is 31.84%, and if combined with district heating system, the IRR is 8.92% since the profit for district heating system alone is very low as 3.13%. However, in reality, this kind of infrastructure project is normally subsidized by the central government. There will be no loan or just a small part. And for heating consumers the government will give substantial support. In this case, by assuming without paying loan interest of district heating system, the IRR can be raised to 10.78%. As the MARR of the company is defined to be 10%, then this entire project can be economically feasible.

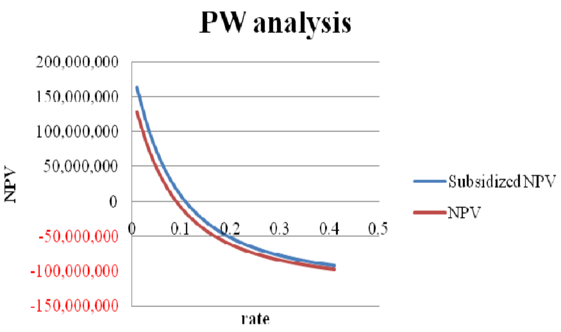

Figure 30: NPV as a function of rate of return for CHP plant

CONCLUSIONS AND SUGGUESTIONS

Based on the energy assessment and utilization status in Tibet, the proposed project of geothermal power generation and district heating system is designed and analyzed to investigate the technical and economical feasibility. The results show that all alternatives are technically feasible. Three of them are CHP cycle (i.e. including heating capacity), only Scenario 3 optimized as a pure ORC cycle double flash power cycle has no heating capacity. The power output of each scenario is about 18MW, 22MW, 29MW, and 25MW, respectively. The thermal efficiency of each power cycle is 5.27%, 5.99%, 8.46%, 7.50%, respectively. Whereas, including heating capacity, it increases significantly to be 39.12%, 36.53%, and 37.74% for Scenario 1, 2 and 4. Therefore, Scenario 3 yields the maximum electricity at the highest efficiency of 8.46%, and Scenario 1 works at the maximum total thermal efficiency of 39.12% by producing both power and heating.

District heating system study is carried out based on the heating capacity of 114MW from Scenario 1 which can supply 40% of the total heating demand of 273MW. The heated water will be transferred to Lhasa via 90050m long transmission pipeline with the diameter of DN500. The supply temperature is 85 ºC and the temperature drop along the pipeline is about 5 ºC.

The economic evaluation for all power cycles and district heating system shows that the most financially viable scenario is Scenario 1 as a double flash cycle with IRR of 31.84%, followed by Scenario 2, 4 and 3 with IRR value of 22.15%, 14.86% and 9.57% respectively. District heating system is low profitable since the high investment cost of long distance transmission pipeline with IRR of 3.13%. By combining the most financial feasible power cycle, the CHP power plant and district heating can get IRR of 8.92%. If considering the support from government, without loan interest payback, this IRR value can increase to be 10.78%, which means if MARR is 10% from the investment company, it is economically feasible.

In district heating system construction, it is recommended to develop other heating source to reduce the peak load during the severe period in winter, so that the distribution system of long distance heating system can be expanded. It would give better profitability. The other heating source is recommended to be ground source heat pump system, or in some cases, the oil or gas boiler can also be applied just for supplement the peak demand.

This research works out the optimum solution for CHP power plant in terms of technical and economical feasibility. Meanwhile, the environmental concern also should be emphasized all along. The fragile ecological and environmental conditions in Tibet urge more care when implementing such infrastructure projects especially the long distance district heating system. The construction of this project is not only an effort to improve local people's living standard, but also to prevent progressive deforestation. At the same time, the utilization of such renewable energy is also in line with the themes of sustainable development.

REFERENCES

Andre Alexander and Pimpim de Azevedo: The old city of Lhasa. Report form a conservation project (98-99) http://www.asianart.com/lhasa_restoration/report98/

Peter Randlov, District Heating Handbook, European District Heating Pipe Manufacturers Association, 1997.

Ecological Improvement and Environmental Protection in Tibet, http://news.xinhuanet.com/zhengfu/2003-03/11/content_771404.htm

Hui Ren, Electric Power Industry in China, University of Wisconsin-Madison North China Electric Power University, PSERC Tele-Seminar, Feb. 6th , 2007

Japanese International Cooperation Agency, Yangbajain geothermal resource reservoir assessment and exploitation plan final report (Simplefied version), 2006.2 (in Chinese).

Karlsson, T., Geothermal district heating The Iceland experience, UNU-GTP Report 4, Iceland 1982, 116 pp.

Leland Blank and Anthony Tarquin: Engineering economy, Fifth edition, the United States, 2002.

Valdimarsson, P., Modelling of Geothermal District Heating Systems, Ph.D. Thesis, University of Iceland, Faculty of Engineering, Reykjavik, Iceland 1993, 121 pp.

Wang Hua, Wei Jianfeng, and Liu Dongsheng, Project proposal of district heating system by using Yangbajain power plant discharge geothermal brine in Lhasa, 2006,6 (in Chinese)

Weather data Source in China, U.S. Department of Energy, Energy Efficiency and Renewable Energy, http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=2_asia_wmo_region_2/country=CHN/cname=China

Zhen Keyan, Giving full play to geothermal in renewable energy development in Tibet, China, Proceedings of the 7th Asian Geothermal Symposium, July 25-26, 2006