STUDY OF ENVIRONMENTAL IMPACT IN GEOTHERMAL DEVELOPMENT AND UTILIZATION

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ABSTRACT

Geothermal resources are the clear "green" energy sources, as the alternate energy sources of the fossil fuels such As coal, oil and natural gas, their development and utilization have an important significance for reduce "the greenhouse effect" and improve the people's environment. But during the processes of geothermal development and utilization the different environmental problems could be induced by not good at management, willful discharge or emission of pollutant without any treatment, super-exploitation, etc. These issues could influence the sustainable development of geothermal fields to a certain extent. For these reason, many countries has paid a great attention to these issues. Based on referring and citing a part of relevant literatures and materials, in the paper are discussed the environmental impact issues including water and soil pollution, air pollution, thermal pollution, subsidence and landslide hazard, which may be occurred during the processes of geothermal development and utilization, and several proposals are offered.

Keywords: geothermal development and utilization, environment pollution, surface subsidence, landslide hazard, suggestion

1. INTRODUCTION

Geothermal resources are the clear "green" energy sources. Considerable progress has been made in the development and utilization of geothermal resources in different countries of Asia. It contributed to reduce the "greenhouse effect" and improve the people's environment. In recent years, because of the war in Iraq the oil cost increased and floated slightly, the energy sources are in short supply, the development and utilization of geothermal resources which are one of alternative energy sources of the fossil fuels such as coal, oil and natural gas, are faced with new opportunity and new challenge. If to say that the 70th of the twentieth century was the first high tide of geothermal development in the world, up to the early in the twenty first century it stepped into the second high tide.

However, because of not good at management, willful discharge or emission of pollutant without disposal, super-exploitation, etc., during the processes of geothermal development and utilization the unfavorable impact on surrounding environment will be caused: (1) waste water, waste gas, waste heat of geothermal water after uses can cause an environmental pollution including the water pollution, air pollution and thermal pollution, and constitute a hazard to water, air, soil, crops and biota; (2) The environmental impact can be caused by super-exploitation was underestimated before exploitation of geothermal field, so, in the early stage of development in several geothermal fields the pressure of geothermal reservoir decreased and resources dried up leading the subsidence, deformation and other environmental issues; (3)The geological hazards such as landslides and slope failure hazards occurred maybe in several locations of hydrothermal alteration zones in the high-temperature geothermal active areas. These environmental issues effect the sustainable development of geothermal fields, at the same time, they could also seriously threaten and destroy the facilities such as power plant and pipelines, road and other parts of the infrastructure.

The governments of many countries in the world attach a great importance to multipurpose development and utilization of geothermal resources as one of the renewable energy sources. The different departments have formulated the preferential policies and relevant legalities and rules to encourage the private enterprises to invest actively their money for geothermal development and utilization and participated the international or regional cooperative projects.

And a great works have been carried out for strengthening the resource protection and management and reducing the environmental impact of geothermal development in the country (B. Chu, 1991; Zheng, K. and Huang, S.: 2003; Q. Tao, 2004; J. Wu, 2004; J. Chen, 2004; C. Li, 2004; N. Hong et al., 2004; Y. Yang, 2004; K. Zheng et al., 2005; D. Bin et al., 2005).

In order to realize the sustainable development of geothermal resources, to decrease and prevent happening of water and soil pollution, air pollution, thermal pollution, surface subsidence, landslides and other, and to mitigate possible environmental impact, a number of countries of the world has taken corresponding with them measures of the preventive treatment, and the preliminary results have been obtained.

At present, because of fund shortage, backward in technique and other reasons, the environmental impact is still relatively outstanding issues in several places. In the paper are mainly discussed the environmental impact problems including water and soil pollution, air pollution, thermal pollution, surface subsidence and landslide hazard, which may be occurred during the processes of geothermal development and utilization, and several proposals are offered.

2. WATER AND SOIL POLLUTION

The geothermal waste waters discharged after uses have generally higher salinity and contain pollutants as F, B, Hg, As. Parts of pollutant contents exceed that of the water quality standard for drinking water, irrigation water and aquaculture water. If the waste waters after geothermal development and utilization the unfavorable impact on surrounding environment will be caused by not good at management, willful discharge or emission of pollutant without any treatment. Especially, they entered into surface water body or underground water body, or infiltrated into the ground soil, the later could be polluted, the water quality worsened, and the people's health can be harmed and ecological environment can be destroyed. For example, in Yangbajain of Xizang, China, the quantity of waste water discharged from Yangbajain geothermal power station was up to 700m^3/d, leading to form relatively seriously polluted region with an area of about 14km^2, where the contents of harmful elements in the underground water body and surface water body exceed greatly that of the national standard for drinking water., and the water in Lhasa River was also polluted to a certain extent (Duan Y. et al., 1993).

2.1 Mineralization (M)

Mineralization of geothermal water is usually higher, except of water pollution, the salinization of soil is formed. According to J.Wang and J. Zhou (1992), since 1985 the geothermal water of well Ma No.16. in Hejian Region of North China plain has been utilized for greenhouses, space heating and fishing farming. The geothermal water has a mineralization of 6.4g/l and F content of 7.89mg/L. After uses the geothermal wastewater discharged into nearby pool and lowland, the underground water body and soil were polluted. Because geothermal wastewater has infiltrated into underground water and recharged it, the ground water level was obviously elevated, leading to the serious accumulation of salt on the surface of soil, and it effected directly the ecological environment.

2.2 Fluorine (F)

The content of F in geothermal water is often higher. In many places it changes greatly, mostly between 2～16 mg/L. The contents of F in geothermal waters of Beijing and Tianjin were of 5.9 mg/L and 3～10 mg/L, respectively (K. An, 1993); in Yanbajain geothermal field it was of 12mg/l (Grimaud D., S. Huang, G. Michard and K. Zheng, 1985; S. Huang, K. Zeng et al., 1985). The geothermal waters of Puga, India and of Kizildare, Turkey, contain 15mg/l (Shanker et al., 1975) and 21mg/l (Ten Dam A., Dominco E., 1971). If person spot tooth and drinks frequently water with high content of F, exceeding greatly that of national standard, the diseases of fluorine bone could be caused. In several regions of geothermal water distribution in North China the incidence of these diseases is relatively higher, but if drinking the treated water after water fluoridation, the incidence of the fluorine spot tooth disease started lower. Since December 1988 to date, M. Yang et al. (2005) has carried out the systematic hygiene study of the environmental impact of geothermal wastewater during about 20 years in village Gui'an of Lianjiang city in Fuzhou Region. The detected results indicate that the geothermal wastewater without treatment inflows into streams and rice field and caused the unfavorable impact on surface water body, soil and crops. The contents of F in geothermal water are of 7.1～16.1 mg/L, and in the irrigation water on distances of 50m and 100m they are of 12.10 mg/L and 6.15 mg/L, respectively, and exceed obviously that of standard (3 mg/L), and the crops was also polluted by geothermal wastewater. When the geothermal wastewater was utilized for fish breeding the content of F in the fish body increased with increase of F content in the pool water. For example, the content of F in pool No.3 was of 3.35 mg/L, it was of 4.280±0.419 (3.10～5.70) in fish body, they were all exceed that of the food hygiene standard (2mg/kg) in our country. It is clear that neither to utilize the geothermal wastewater of this type for irrigation nor to utilize it for fish breeding.

2.3 Arsenic (As)

Arsenic (As) is one of the main pollutants in the chemical composition of geothermal wastewater. The content of As in high-temperature water is higher. In geothermal fluid of Yangbajain in Xizang (Tibet) it was of 2.81mg/L (Grimaud D., S. Huang, G. Michard and K. Zheng, 1985 ; S. Huang, K. Zheng et al., 1985), in Tagejia Geyser water it is of 5.4 mg/L (W. Tong, M. Zhang et al., 1981). The concentration of As in geothermal fluids of the Paudjetka power plant in Russia was of 7.5 mg/L (Kononov, 1983).

The geothermal waters caused water pollution and harmed to inhabitants, crops and domestic animals. Jenny G.

Webster-Brown and Vincent Lane (2005) described the environment harm of As being released from geothermal fields into river system in New Zealand. In the central North Island of New Zealand the As is released from geothermal wastewater directly into the Waikato River. Arsenic concentrations in the river water typically range from 0.02 to 0.06 mg/L. It is of 4.8 mg/L in geothermal fluid of the Wairaki (Ellis, 1975 ; Ellis, Mahon, 1977). It can lead to form water pollution in geothermal active catchments. Arsenic in the weed caused directly harm to the people's health, wildlife and plant and farm animals. There is an evidence of cattle poisoning through eating weeds from a hydroelectric lake on the Waikato River.

According Yuuji Hamada et al.(2005), in Hatchobaru of Japan, the released arsenic removal commercial plant and treated water supply system to hot spring resorts have been developed by Kyushu Electric Power Co., Inc. (KEPCO). In this plant, arsenic concentration of geothermal water was reduced from 3-4mg/L down to the value less than 0.01mg/L that is the upper limit of environmental regulation for treated water in Japan and satisfied an environment standard value (0.01mg/L). The treatment capacity of the plant was 100t/h of the water at maximum. The plant is also free from a silica scaling problems as the water is treated in low pH range. The treated water through arsenic removal can be utilized effectively for multipurpose uses.

2.4 Boron (B)

In geothermal fluids of many high-temperature geothermal fields in the world, the boron concentration is very high. the H_3BO_3 concentrations in Geysers of and Salton Sea of America are of 85.8 mg/L (White et al., 1971) and 2232 mg/L (Muffler and White, 1969; White et al., 1971), respectively. The HBO_2 concentrations is of 648 mg/L in the Matsukawa of Japan (Ellis, Mahon, 1977). In Dieng geothermal fluid of Indonesia the boron concentration is of 480mg/kg. Released B caused the harm to crops. In order to protect the environment the separated geothermal wastewater will be reinjected into geothermal reservoir (Radja Vincent T. and Didi Sulasdi, 1995).

According to Mebrure Badruk and Hasan Mordogan (2005), in the Denizli-Kizildere geothermal fields is the first geothermal field that suitable for electricity production situated on the Western Anatolia in Turkey. The wastewater disposed away from the power plant has a capacity of 1500tons/h. The wastewater from Kizildere geothermal brine contains boron approximately 30 mg/dm3. Therefore the permitted level of boron in irrigation water is 1 mg/dm3. So, it exceeds greatly the standard value. High concentrations of boron are particularly detrimental for citrus fruits. In order to use this geothermal wastewater for irrigation in Kizildere agricultural areas, experimental work was carried out to investigate the optimum conditions of boron removal from Denizli-Kizildere Geothermal brine by utilizing co-precipitation method.

In Yangbajain Geothermal field of Xizang, China, the HBO_2 concentration is of 240 mg/L, in Dagejia Geyser it is of 440 mg/ L (W. Tong, M. Zhang et al., 1981). L. Yan (1994) suggested that the borax can be extracted from geothermal wastewater (80℃) of Yangbajain power station and the technological method for extraction of borax has been advanced. It is considered that the wastewater and waste residue with micro-content of boron can be also used as fertilizer.

2.5 Mercury (Hg)

Geothermal steam contains often the mercury (Hg). Generally, the Hg diposition is obviously related with geothermal activity. The Hg concentrated often in geothermal field and its surrounding areas, and polluted water body and soil, threatened the people's health and normal grow of crops. According to B. Zhu and H. Yu (1994), an average content of soil Hg in Yangbajain geothermal field of Xizang and in Rehai of Tengchong are of 265 mg/L and 149 mg/L, respectively.

Study of emission of Hg-bearing steam has been carried out and Christenson et al. (2002), Mroczek (2005) have investigated the chemical process leading to form the high concentration of Hg in geothermal power plant and its surrounding areas. The research deals mainly with toxicity of Hg, prevention of oxidation and biological cumulating characteristics. In order to mitigate the environmental impact caused by Hg steam emission, Aldo Baldacci et al. (2005) advanced technical method for removal of Hg and H2S, and considered its efficiency can be up to 99%.

In the early stage of geothermal development in China, the famous hydro-geologist of our country, Prof. D. Wang has pointed out that florin, arsenic and boron whether they are in water or in steam from geothermal plant, are all can cause pollution. The related issues should be rapidly studied and resolved (D. Wang, 1981). At present, in many countries of the world in order to avoid or mitigate the pollution to water body caused by harmful elements in geothermal wastewater, which heated the cold underground water or river water through heat exchanger, after this, the wastewater was injected into geothermal reservoir or discharged after treatment by removal of F, As, B or others, and the distinct effect has been obtained.

3. AIR POLLUTION

During processes of geothermal development and utilization the harmful gases emissions as H_2S and CO_2 often contaminated the air seriously, and endangered the people's health and the ecological environment.

3.1 Hydrogen Sulfide (H_2S)

In the non-condensible gas emission from geothermal fluids after uses the H_2S is the main gas. The H_2S contents in high-temperature geothermal fluids in the world are common and higher. It is of 6 mg/L in Yangbajain of Xizang, China (D. Wang, 1981). The Matsukawa geothermal field in Japan has H_2S content of 5 mg/L (Nakamura and Sumi, 1967). The H_2S content is up to 16 mg/L (Muffler and White, 1969). When H_2S concentration emission from geothermal fluid is high, its toxicity will be very great, In relation to this, the person and biota as flying bird, insect and fish can be asphyxiated and died. When the H_2S concentration is lower, it emitted bad odor, that is difficult to accept for workers and local inhabitant, and the diseases of eyes and nose after stimulating can be easily induced. Therefore, study of H_2S abatement is very important.

According to Kazuo Takahashi and Mitsuru Kuragaki (2000), although the H_2S that was released from Yanaizu-Nishiyama geothermal power station has a very low concentration range of 6-60 ppb, but the H_2S odor polluted the air for long time. For protecting the environment the H2S abatement system was constructed in 1998. Its efficiency is over 90%. Wayne D. Monnery (2005) Discussed also the technology of H_2S abatement and sulphur recovery. The capital and/or operating costs are low and some processes are easy to operate.

3.2 Carbon Dioxide (CO_2)

The development and utilization of geothermal energy as a clean energy sources alternated partly the conventional energy sources, reduced a great deal of CO_2 emission from power plant with fossil fuel, at the same time, it reduced "the greenhouse effect" and contributed to improve the human environment. Italy is one of the famous advanced countries of geothermal development in the world. According to Aldo Baldacci et al. (2005), in 2003, electricity from geothermal resources total led more than 5 billions kWh, which represents approximately 2% of the electricity generated in Italy. This share rises up to about 25% in the Region of Tuscany, where almost all geothermal development is concentrated. Geothermal generation has allowed Italy to save the consumption of 1.2 million TOE (tons of oil equivalent) of fossil fuels and to avoid the emission of 3.7 million tons of CO_2. The new geothermal plants planned for the next years will contribute to CO_2 emission reduction required to fulfil Italy's Kyoto commitment (reduction of 6.5% of CO_2 emission in the period 2008～2012 compared to 1990).

Valentina Svalova (2005) discussed the relevant issues of geothermal resources and environment, and pointed out an especial importance of environment issues in geothermal energy use in connection with global climate changes problem and Kyoto Protocol ratification in Russia. On June 27, 2002, the Russian Government approved the Action Plan including the greenhouse gas (GHG) emissions reduction. According to Alexey V. Kiryukhin et al. (2005), there are five exploitation wells which supply steam for the 50MWe Mutnovsky geothermal power plant , located in Kamchatka of Russia. Current greenhouse CO2 emission is 1,132 tons annually, and 2.6 kg / MWh of CO2 per has an environmental impact from Mutnovsky power plant. This is significantly lower than that of coal-based, gas-based and oil-based power plants, they are 550kg/MWh of CO2, 850kg/MWh of CO2 and 1000 kg / MWh of CO2, respectively. Hence, CO2 reduction in Kamchatka due to the Mutnovsky geothermal power plant reaches 245,000 tons annually. The price of 1 ton of CO2 is estimated as 5 US dollars (Guidelines, 2003) in the world market of CO2 quotas according to Kyoto Protocol principles. That makes the potential benefit for the Mutnovsky project (at current rates) an annual amount of 795,000～1,450,000 US dollars.

On the other hand, CO_2 is the main gas emission from geothermal power stations. Its percent contents is very high, mostly range between 50～90%. In Larderello of Italy and Paudjet of Russia CO_2 contents are of 92.8%及72.6% (Kononov, 1983), respectively. Yangbajan of Xizang Autonomous Region in China and Macao of Taiwan Province in China have CO_2 contents of 97.0% Grimaud D., S. Huang, G. Michard and K. Zheng, 1985; S. Huang, K. Zheng et al., 1985) and of 92.0% (Ellis, 1979), respectively. Although in many instances CO_2 contents of waste gas emitted from geothermal power plants are lower than that of power plants with fossil fuel combustion, many countries devoted still much attention to the environment issues related with CO_2 emission from geothermal development.

Chris J. Bromley (2005) studied in detail the relevant issues of geothermal environmental management, and pointed out that over the past five years, advances have been made in environmental management of geothermal developments, worldwide, and particularly within those countries participating in an Environmental Annex of the Geothermal Implementing Agreement of the International Energy Association. Collaborative research is being undertaken in Iceland, New Zealand, Italy, United States and Mexico to address these issues (Armannsson, 2003, Sheppard and Mroczek, 2004). Carbon dioxide injection possibilities are also being addressed (eg: White et al, 2003). CO_2 emissions

from geothermal power plants were surveyed and published by Bertani and Thain (2002) and Armannsson (2003). The worldwide weighted average of emitted CO_2 was 122g/MWe, but with a large range from 4 to 740g/MWe.
In order to reduce the amount of CO_2 emission and to curb global warming, A. Ueda et al. (2005) and Hisantoshi Ito et al. (2005) have carried out an experiment in the laboratory and test in the field of CO_2-water-rock interaction at Ogachi, northeast Japan. Preliminary results indicate that injected CO_2 may react with surrounding minerals, e.g., Ca feldspar and anhydrite, and may precipitate $CaCO_3$, forming cap rocks. It is considered that CO_2 sequestration by injection into geothermal fields could be practicable and the method .to sequester CO_2 into the Earth's Crust as carbonates, is a promising method.

4. THERMAL POLLUTION
Large number of geothermal wastewater from power stations and greenhouses are discharged after utilization in several geothermal fields of China. The wastewater has yet a temperature of 40～50℃, even 60～70℃. It was not sufficiently utilized and was abandoned that not only wasted an energy source (S. Huang et al., 1986), but also caused thermal pollution. The temperature of geothermal wastewater exceeds greatly the discharging temperature standard of our country (35℃). Radja Vincent T. and Didi Sulasdi (1995) studied the possible unfavorable environmental impacts during different power plant operation in Indonesia. The separated geothermal water not only polluted water body and atmosphere, but also caused thermal pollution. Geothermal wastewater from Lahendong geothermal field has the temperature of up to 130℃, significantly higher than the 28℃ temperature of the river water. After it mixed with river water, the temperature of the latter will increase up to 90℃,resulting in thermal pollution. For preventing the occurrence of thermal pollution and mitigating the harms to fish and crops, the high-temperature wastewater after integrated uses should be reinjected into geothermal reservoir, or discharged after utilized or cooled.

5. SURFACE SUBSIDENCE
The surface subsidence is one of the geological hazards occurred during the processes of geothermal development and utilization and caused by super-exploitation of geothermal fluids. In recent years, in China the geothermal market has been steadily broadened out, the economic effect is very obvious (S. Huang, 2004, K. Zheng et al., 2005). On the other hand, in some places the geothermal water was over-exploited, resulting in descending of water level year after year. By this reason the resources dried up and affected seriously the sustainable development (S. Huang, Y. Yang, 2002). In 1991, the vaporized surface in production well of Yangbajain geothermal field in China declined 20～45m, the maximum value of surface subsidence was of 176.6mm (Dunzhujiacan, Y. Zeng,1998).

According to Barbara Ciulli et al. (2005), since 1973, when industrial exploitation of the Travale-Radicondoli geothermal field started, ground vertical movements have been monitored by means of precise topographic leveling. Over the past 30 years a maximum subsidence of 50 cm has been measured; the initial rate being 2.3 cm/year has progressively decreased to the current 1 cm/year.

Ewa Glowacka et al. (2000) presented in detail the subsidence issues of Cerro Prieto geothermal field in Baja California of Mexico. The long-term monitoring data indicated that during the period 1977 - 1987 the subsidence rate at the center of the Cerro Prieto Geothermal Field increased after every large, sustained production increase. Maps of subsidence rate for 1994 - 1997 show that the area with a subsidence rate≥ 8 cm/y has an elliptical shape with a NE-SW major axis, which coincides with a thermal anomaly and with the orientation of a pull-apart basin located between the Cerro Prieto and Imperial faults. The area of maximum subsidence rate, around 12 cm/y, coincides with the area of extracting wells.
Chris J. Bromley (2005) suggested that not all occurrences of subsidence in geothermal areas are attributable to deep reservoir pressure drawdown; some are caused by shallow processes such as groundwater level changes (Bromley and Currie, 2003), thermal clays, or poorly-compacted fill placed within thermal gullies and depressions. Before mitigation or avoidance measures are put into place, the correct mechanism must be identified.

6. LANDSLIDE HAZARDS
During geothermal development and utilization the geological hazards such as landslide, rockfall, slope failure and others distribute mostly in the hydrothermal alteration zones of high-temperature geothermal active regions. There are many high-temperature geothermal active regions In Xizang– Yunnan Geothermal Zone located in the western part of China and in West Pacific Island Arc Geothermal Zone, located in the eastern and south-eastern part of China. Because high-temperature geothermal fluids, ascending along the tectonic channels to surface, interacted with surrounding rocks, the hydrothermal alteration zone was formed. These localities often became frequently-occurring areas of landslide hazards.

Winston Philip C. Pioquinto and Joeffrey A. Caranto (2005) described in detail the landslides and slope failure hazards, distributed commonly in PNOC-EDC geothermal fields and the serious harms to environment caused by these hazards and the implemented measures by PNOC-EDC for mitigrating the impact of landslide hazards. The PNOC-EDC geothermal fields, especially high temperature geothermal fields of PNOC-EDC, mostly located in volcanic areas, are characterized by high relief, rugged terrain and high rainfall rate. This situation is further aggravated by the presence of inherently weak thermally altered rocks and sometimes fumaroles and mud pools above the slopes. These landslide hazards destroyed road, cut-off pipelines and even obliterated a geothermal well pad resulting to plant shutdowns thus, loss of revenue and had become an enormous threat to PNOC-EDC operations. Coping with these landslide hazards therefore has been one of the major concerns of PNOC-EDC. For mitigrating the impact of landslide hazards it is necessary to adopt following measures: (1) assessment of landslide hazards in the early stage of geothermal development and avoidance of high risk areas for constructing the plant, road and pipelines; (2) protection or prevention, strengthening land management and prevention undue mass wasting; (3) reduction or elimination of the detrimental effect of slope movements in case of rockslides and rockfalls, galleries or pipe shelters could be constructed to protect the concerned installation (Fig. 1); (4) Remediation aimed to stop or reverse the destabilizing process using engineering measures, including benching, drainage control, structural barriers and vegetative stabilization. In the case of critical sites extensometers and tilt meters were installed for constant monitoring of any slope movement.

There are many landslide bodies with different sizes in the hydrothermal alteration zone near Huangguaqing Fumarole Area of Tengchong Rehai in Yunnan of China. One of the landslides ia shown in Fig. 2 (by Shangyao Huang, January 1980). The special study was not carried out. Obtained valuable experiences of studying landslide hazards and coping with them in geothermal development and utilization in Philippine PNOC-EDC geothermal production fields, presented by Winston hilip Philip C. Pioquinto and Joeffrey A. Caranto (2005) are worth using for references.

7. CONCLUSION AND SUGGESTION

To sum up, in development and utilization whether high-temperature or medium-low-temperature geothermal resources of different countries in the world the unfavorable environment impacts can be occurred to some extent. Firstly, water pollution, air pollution and thermal pollution caused by wilful discharge or emission of geothermal waste water, gas and heat, destroyed ecological environment and harmed to the people's health. Secondly, because of super-exploitation the water lever was declined continuously, resources dried up, leading occurrences of surface subsidence and deformation and influenced the life of geothermal fields. Thirdly, because of widespread distribution of hydrothermal alteration zones in high-temperature geothermal active regions, the geological hazards such as landslides, slope failures and others occurred easier and aggravated. They threatened directly normal operation of power plants and destroyed pipelines, road and other infrastructures. Such above environmental issues affected directly sustainable development of geothermal resources. In order to mitigrate the environmental impact the following suggestions are advanced: (1) Deepening the understanding of environmental impact and its serious consequences and strengthening scientific management; (2) The harmful elements in geothermal wastewaters, gases and their temperature should be accorded with that of emission standard. The harmful elements such as B, H_2S, CO_2 should be treated and recovered and studied the relevant technology and method for "turn bane into boon", "turn waste into wealth"; (3) the heat of geothermal wastewater should be utilized enough, after this the water will be reinjected into reservoir and it is necessary to carry out the studying on the reinjection and trace test; (4) In order to realize the sustainable development, it is necessary to strengthen the monitoring of exploitation regim, strictly control the amount of exploitation, hold stable water pressure and temperature and decrease the subsidence rate; (5) in order to mitigrate the environmental impact caused by landslide hazards the special investigation and specialized study on geological hazards including landslide, rockfall, mud-rock flow, slope failure and others, occurred often in the hydrothermal alteration zones of high-temperature geothermal regions, should be carry out.

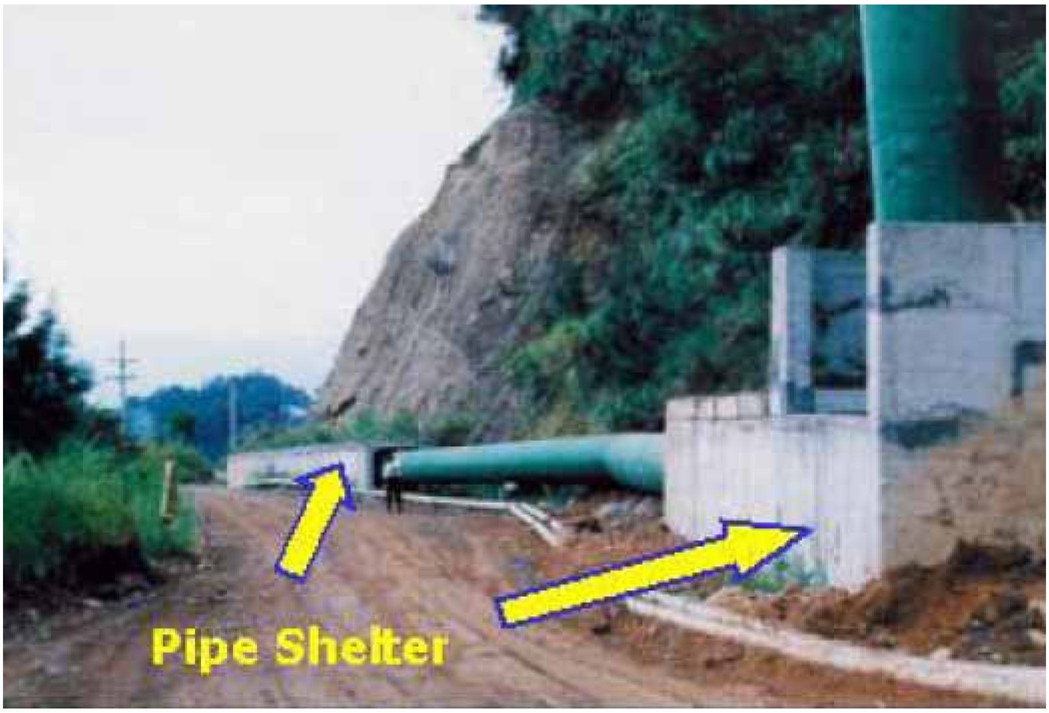

Figure1 Pipe shelters were installed along some portions of the FCRS route above pad E in MGPF as this site is prone to rockslides and rockfalls.

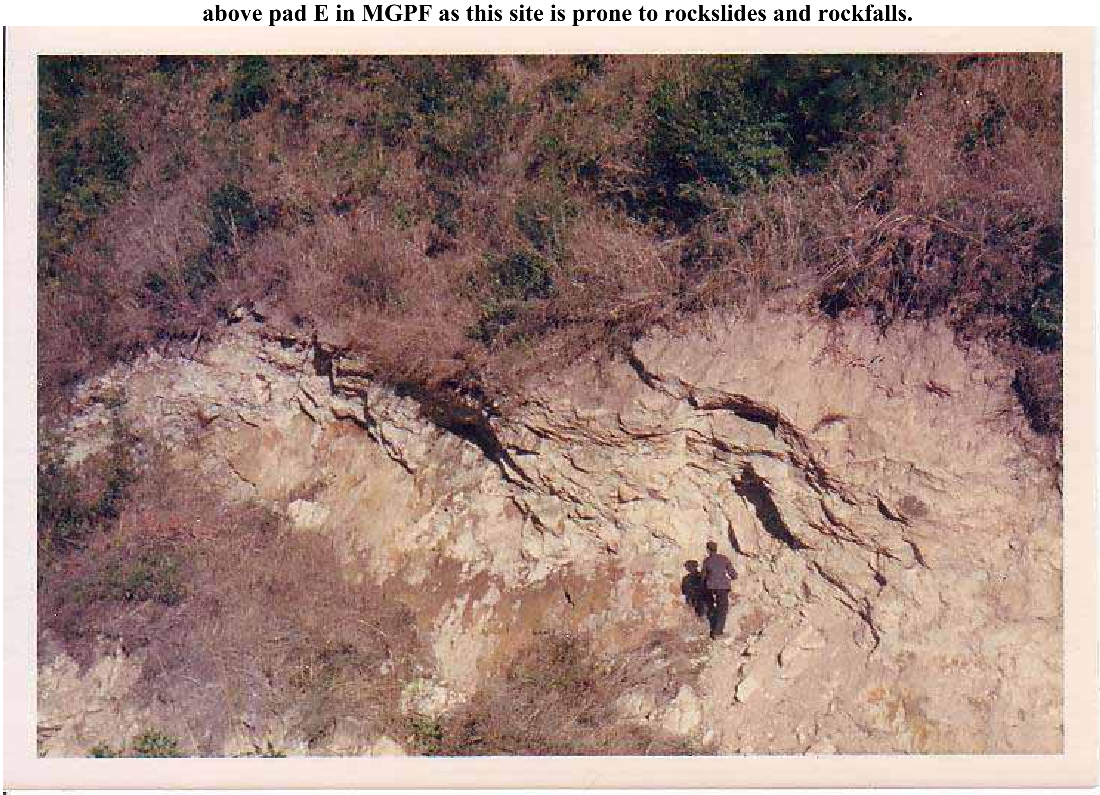

Figure2 One of the landslides in Hydrothermal Alteration Zone near Huangguaqing Fumarole Area of Tengchong Rehai, China (Photo, by Shangyao Huang, January 1980)

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