

An Overview of EGS Development and Management Suggestions

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ABSTRACT

The world is facing the energy challenge to over-reliance to fossil-fuels, the development of renewable energy is inevitable. From a clean and economic view, enhanced geothermal system (EGS) provides an effective mean to utilize geothermal energy to generate. Different from the conventional hydro geothermal, the host rock of EGS is Hot Dry Rock (HDR), which buries deeper with high temperature (more than 180°C). The generation of EGS is promising. The development of EGS can be combined with the tech Power to geothermal energy. Exceed power is supposed to drive fluid working in HDR layer to obtain geothermal energy for generation. The whole article can be divided into three parts. In the first art, evaluation indexes of EGS as well as pilot EGs Projects (e.g. Fenton Hill and Basel) and exiting EGS project (e.g. Paralana and Newberry) are summarized, which points a general impression on EGS site. The dominate indexes are heat flow, geothermal gradient and thermal storage. The second part is focused on the simulation methods and working fluids selection of EGS. A detailed comparison of the main simulation software (e.g. TOUGH2 and FEHM) is carried out. With the respect of working fluid selection, the comparison between water and CO₂ is researched and CO₂ is a preferred option for EGS development for less fluid loss and less dissolution to HDR. The art of CO₂-EGS is introduced clearly in this part. The third part is about the addition consideration of EGS plant operation, it includes auxiliary plant support and HSE management.

1. Introduction

1.1 Energy Challenge

Energy transition has been discussed worldwide over decades. The world is under the status of over-reliance on fossil-fuels in various fields. According to the BP Statistic 2019, from 1993 to 2018, global energy consumption increases year by year (Figure 1) and fossil-fuel dedicates a great share. Among them, coal occupies the first with a consumption of 14000 million tons oil equivalent. The great share of fossil-fuel is not a coincidence. Figure 2 depicts the trend of shares of

global primary energy consumption by fuel and the top three are oil, coal and natural gas. All are fossil-fuels. The shares of hydroelectricity, nuclear energy and renewable energies are all below 10%^[1]. As a consequence, the carbon dioxide emissions raise to 33890.8 million tones and it increases by 2% compared with 2017. Obviously, the domination and over-reliance of fossil-fuels in primary energy consumption is not a suitable way for sustainable development. Energy transition is an evolution to increase the share of renewable energy and improve the energy efficiency. In 2018, the world renewable energy consumption is 561.3 million tones oil equivalent and it increases by 14.5% compared to 2017. The renewable energy con-

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sumption excludes the gross generation from renewable energy sources including wind, geothermal, solar, biomass and waste. The capacity of power generation of renewable energy is expanding in recent years, especially wind power and solar power. According to IRENA's latest data, global installed wind-generation capacity onshore and offshore has increased by a factor of almost 75 in the past two decades, jumping from 7.5 GW in 1997 to some 564 GW by 2018^[2]. Solar power also shows a promising potential for a similar capacity to the wind power. Solar power contains the power generation from solar thermal and solar photovoltaic also known as solar PV. The whole installed capacity of solar power in 2019 is around 586 GW, of which solar PV contributes 580 GW^[3]. Not only is the expansion to increase the share of renewable energy in power generation, but an effective method to improve energy utilization efficiency also important for energy transition. Since there is always a time gap between power generation and power use. Normally, the power demand in winter season is high while the demand is relatively low in summer season. From a daily view, power peak often comes in the early morning and evening, while the afternoon is a time of power surplus. Energy storage provides means to store the surplus power as other forms when power is in low demand and generates when power is in high demand. It is called power to X and X refers to the storage forms. When the storage form is chemical gases (e.g. natural gas and hydrogen), it is called power to gas. When the generation energy is converted and supported by the gravity potential energy, it is called power to gravity potential energy and the corresponding storage medium is water. When the tech is combined with geothermal energy, it is called power to geothermal energy.

In this paper, power to geothermal energy is focused and discussed. Geothermal energy refers to the thermal energy that exists in the earth's internal rock, soil, fluid and magma bodies and can be developed and utilized. Depending on its characteristics, geothermal energy can be used for direct heating, geothermal heat pumps and be harnessed to generate clean electricity. The technology for electricity generation from hydrothermal reservoirs with naturally high permeability is also mature and reliable and has been operating since 1913^[4]. Geothermal power has been expanding since the 1950s. As of 2010, a total of 24 countries have geothermal power plants with a total installed capacity of approximately 11 GWe^[5]. Liu^[6] estimated that 46 countries would have geothermal power plants by 2015 with a total installed capacity of approximately 19 GWe. The growth of geothermal power from 2010 to 2015 is mainly due to the development of conventional geothermal power plants, especially in the

Philippines, Indonesia, Iceland, New Zealand and the United States. The developments in the Philippines, Indonesia, Iceland, and New Zealand mainly focused on large-scale high-temperature geothermal fields and particularly on steam-type geothermal power generation. The installed geothermal capacity of the Philippines increased from 1904 MWe in 2010 to 2519 MWe in 2015^[7], whereas that of Indonesia increased from 1197 MWe in 2010 to 3451 MWe in 2015^[8]; these were the largest increases in the world. With the development of supercritical geothermal systems, Iceland increased its installed geothermal capacity from 575 MWe in 2010 to 1285 MWe in 2015^[9]. By using binary cycle power generation systems to enhance the efficiency of power generation, New Zealand increased its installed geothermal capacity from 762 MWe in 2010 to 1237 MWe in 2015^[10]. Meanwhile, because of the sophisticated technologies of mining evaluation and low-temperature geothermal heat extraction, the installed capacity of conventional geothermal power plants in the United States increased from 3098 MWe in 2010 to approximately 5000 MWe in 2015^[11-16]. Many of the power plants in operation today are dry steam plants or flash plants (single, double and triple) harnessing temperatures of more than 180°C. In this kind of plants, dry steam or water is the medium carrying the geothermal energy, which is called hydrothermal resources. In the hydrothermal system, high-permeability pores or fissure media provide circulation channels for fluids and geothermal energy can be directly used by mining fluids. Such resources depend on considerable amounts of heat, fluid and low permeability levels in their reservoirs, and the belief based on the current state of the art is that sites which meets all these requirements are rare on the earth. These limitations have forced the scientists to seek alternative solutions so as to minimize the problems entailed and maintain geothermal energy as a viable. Functional power source with a promising future^[17].

Apart from the hydrothermal resources to generate, there is another type of geothermal energy also carrying huge geothermal energy named Hot Dry Rock (HDR) geothermal resources. Different from the host rock in hydrothermal resources, HDR is a rock with higher temperature above 180 C but lower permeability. Normally, there is little fluid in HDR, in some specific situation, even no fluid. So that the geothermal energy in dry hot rock needs to be enhanced by artificial fracturing to form an enhanced geothermal system (EGS). The HDR resources are abundant. For instance, the total HDR geothermal energy ranging from 3 km -10 km underground in mainland China is 20.9×10^6 EJ^[18]. Power to geothermal energy is a tech that allows electricity converts into water or other medium

when the power is in low demand and generates when power is in high demand. The corresponding geothermal system is EGS. Cooling water or other storage medium is injected into HDR layer through the artificial fracturing to exchange heat and then produce hot water or other hot storage medium by using the exceed electricity. When power is in peak demand, the produced hot water or other hot storage medium is going to be used to generate. In the following chapter, the development and methods of EGS are introduced further as well as the available storage and generation medium for EGS.

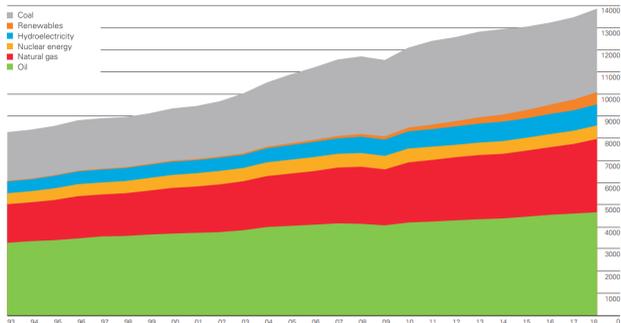


Figure 1. Primary energy consumption from 1993-2018 [1]

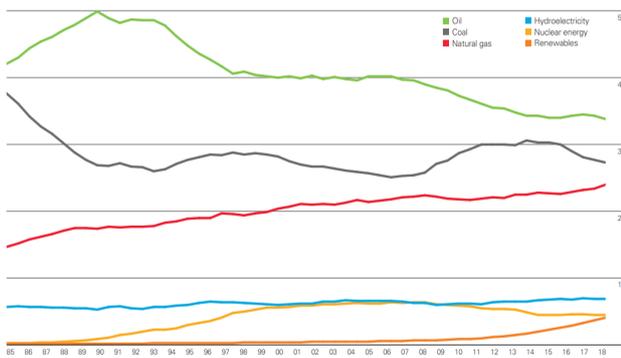


Figure 2. Share of power generation from 1985-2018 [1]

1.2 Objectives

The main object of this work is to study the status of art, technology and research of EGS systems as well as management suggestions for EGS power plant.

2. Evaluation Index of EGS

2.1 Earth Heat Flow Value

The geothermal flow value is a direct thermal parameter, which can quantitatively reflect the geothermal background of a region and is a basic parameter for evaluating the potential of geothermal resources [18]. The geothermal flow at the deep geothermal energy test site in Fenton Hill, USA is $92\sim 247 \text{ mW}\cdot\text{m}^{-2}$ [19]; the geothermal flow at the deep geothermal energy test site in Pohang,

South Korea is up to $80 \text{ mW}\cdot\text{m}^{-2}$ [20]; The geothermal flow at the deep geothermal energy test site in Soultz, France is $82 \text{ mW}\cdot\text{m}^{-2}$ [21,22]; The geothermal flow at the deep geothermal energy test site in Milford, Utah, United States is $(120\pm 20) \text{ mW}\cdot\text{m}^{-2}$ [23,24]. The relative movement between the Mesozoic and Cenozoic plates determines the distribution pattern of terrestrial heat flow in China's land and sea [25] (Figure 1), which is shown in the east (average heat flow value of $65 \text{ mW}\cdot\text{m}^{-2}$) and the southwestern part (average heat flow value of $90 \text{ mW}\cdot\text{m}^{-2}$) High, the middle part (average heat flow value is $55 \text{ mW}\cdot\text{m}^{-2}$) and the northwest part (average heat flow value is $50 \text{ mW}\cdot\text{m}^{-2}$) compared with the global average, which are normally low heat flow values.

According to the distribution of land heat flow in the continental area and the characteristics of the ground heat flow in the existing deep geothermal energy test area, it divided the ground heat flow value into 5 levels, and the representative values of each level are: $90 \text{ mW}\cdot\text{m}^{-2}$ is good; $80 \text{ mW}\cdot\text{m}^{-2}$ is relative good; $70 \text{ mW}\cdot\text{m}^{-2}$ is moderate; $60 \text{ mW}\cdot\text{m}^{-2}$ is relative poor; $50 \text{ mW}\cdot\text{m}^{-2}$ is poor [26].

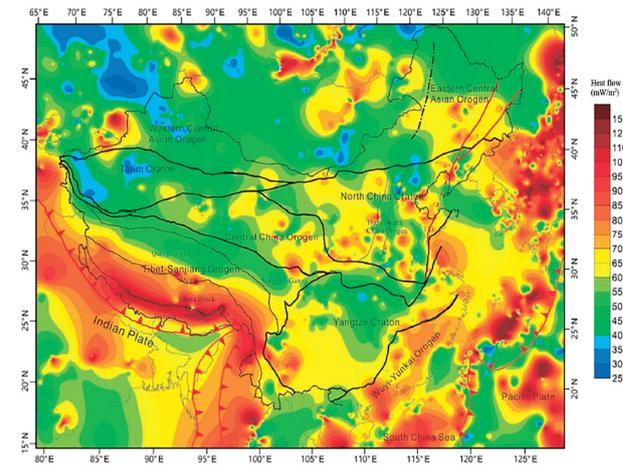


Figure 3. Map of heat flow in mainland China [25]

2.2 Geothermal Gradient

Generally, the average geothermal gradient at the target depth exceeds $30 \text{ }^\circ\text{C}\cdot\text{km}^{-1}$ is regarded as a geothermal anomaly zone. In the western United States, one of the characteristics of power generation-level geothermal resources is that the geothermal gradient is higher than $50 \text{ }^\circ\text{C}\cdot\text{km}^{-1}$ [27-28]. The geothermal gradient of the deep geothermal borehole target reservoir of Fenton Hill in the United States is higher than $60 \text{ }^\circ\text{C}\cdot\text{km}^{-1}$ [29], the bottom hole temperature is above $200 \text{ }^\circ\text{C}$, and the highest is $323 \text{ }^\circ\text{C}$; Pohang deep layer in South Korea The geothermal gradient of the target reservoir for geothermal energy

drilling is $40\text{ }^{\circ}\text{C}\cdot\text{km}^{-1}$, and the bottom hole temperature is $180\text{ }^{\circ}\text{C}$ ^[30]; the geothermal gradient of the target reservoir for deep geothermal energy drilling in Cooper, Australia is higher than $50\text{ }^{\circ}\text{C}\cdot\text{km}^{-1}$, bottom hole temperature is $250\text{ }^{\circ}\text{C}$ ^[31,32], the target reservoir geothermal gradient of deep geothermal energy drilling in Soultz, France is close to $40\text{ }^{\circ}\text{C}\cdot\text{km}^{-1}$, bottom hole temperature is about $200\text{ }^{\circ}\text{C}$ ^[33]. The target geothermal gradient for deep geothermal energy drilling in Milford, Utah, USA is $70\text{ }^{\circ}\text{C}\cdot\text{km}^{-1}$, and the bottom hole temperature reaches $200\text{--}250\text{ }^{\circ}\text{C}$ ^[34].

2.3 Thermal Storage

The EGS technology for artificially constructed reservoirs is the key to the development of deep geothermal energy. The effect of artificially created reservoirs is directly related to the fluid circulation and heat exchange efficiency and determines the economic cost of geothermal development. At present, the reservoir reconstruction technology mainly includes: ① hydraulic fracturing technology, which is to inject a high-pressure water into a closed well hole to cause a large number of cracks near the hole wall, causing the original cracks in the rock body to open and expand. Medium and high pressure water injection connects the fracture zone composed of the crack system between the two wells to form an artificial reservoir; ② Chemical dissolution technology is to inject acidic fluid into the reservoir to make it chemically soluble with the soluble mineral components in the rock Reaction, thereby expanding the pore space. Whether the thermal reservoir rock is easy to be reformed is also an important factor that affects the effect of deep geothermal energy extraction. This should be fully considered during the site selection stage of deep geothermal energy projects. There are many sub-categories of these two types of technical models. As a safer option, the “flexible storage” technology with lower fracturing pressure is gradually favored.

Existing enhanced geothermal systems are dominated by mining sandstone, granite (including granodiorite, mixed granite) and metamorphic rock (including gneiss) reservoirs^[35,36]. Most rock masses have high hardness, dense structure and extremely low permeability. For example, the Fenton Hill deep geothermal energy test site in New Mexico, USA, the reservoir lithology is granodiorite^[37], the EGS project in Soultz, France is granite^[38]. The technical difficulty of EGS is mainly to improve the permeability of hot rock mass and achieve the goal of storage. The harder the rock, the more difficult it is to create and store. The specific problems are: in the drilling process, the hard rock has serious wear on the drill bit, and frequent replacement of the drill bit reduces the construction efficiency and

increases the drilling cost; in terms of thermal storage transformation, natural rocks in granite, metamorphic rock, sandstone and other rock bodies There are fewer void channels, and the effects of hydraulic fracturing and acidification dissolution are poor. In terms of hard rock, the brittleness is strong, the injection pressure is high, it is easy to induce earthquakes, affect engineering safety and system stability, and increase environmental risks^[39,40]. With the continuous development of EGS technology, the engineering technology of extracting deep geothermal energy through artificial storage and storage can be extended to rock bodies that are easier to transform. Medium-thick layer carbonate rocks under high-heat background conditions can be preferred reservoirs. The advantages of this type of heat storage are mainly reflected in the following aspects: ① Carbonate rocks are sedimentary rocks, which are generally distributed in layers and have obvious bedding, which can provide advantageous channels for dissolution and hydraulic fracturing; ② Limestone, dolomite, marble and other carbonate rocks are all soluble rocks, and high-temperature background areas often have high-concentration acid gases such as CO_2 and H_2S , which can promote the occurrence of deep karst processes; ③ Carbonate rocks are Dissolution easily occurs during water injection or acidification, increasing the porosity and permeability of the rock; ④ Carbonate structure in medium-thin to medium-thick layers has dense and short fissures and even distribution, which is conducive to the formation of a relatively uniform fissure network; It is the limited pressure range of acid fracturing, which belongs to the typical “flexible storage” technology. Therefore, the carbonate rock thermal reservoir realizes artificial storage at a lower pressure, and as the fluid heat exchange continues, the circulating fluid will continue to dissolve the surrounding rock minerals, which can further enhance the permeability of the reservoir and improve production efficiency. The above characteristics make carbonate thermal storage become the key target reservoir for deep geothermal energy extraction after the mid-deep hydrothermal system.

3. Development of EGS

3.1 Introduction to EGS Sites

Enhanced Geothermal System, EGS, is an adaption to traditional thermal energy. Different from hydro geothermal energy, the geothermal energy in dry hot rock needs to be enhanced by artificial fracturing. Gallup posed the concept of EGS that EGS system should consist of extracting heat from tight rock that has not fractured naturally, where the permeability is extremely low. Baria

et al. claims that EGS were not viable at first, but technological advancements in recent years have pushed the idea firmly towards commercial operation. The boost given to these techniques includes heat extraction from low-permeability geothermal systems. Stober states that as general rule permeability decreases when pressure increases. MIT predicts that once commercial operations are established, the production of energy from these geothermal resources will increase dramatically all over the world and provides a list of steps for setting up an EGS plant. A general concept of EGS plant is pictured in Figure 4. The first step for EGS is to find a suitable site to create EGS reservoir. The reservoir is supposed to be at a suitable depth to meet the drilling art like 4-5 km and the temperature at such a depth should be as high as possible. Here the reservoir refers to the numbers of areas of HDR where EGS can be applied is exponentially greater. Next, wells are drilled into the hot dry rock, which is stimulated to produce fractures stable enough for fluids to be injected and circulate through it. The fractures provide the permeable pathways. Through these fractures, cooling injected fluids are intended to exchange temperatures from heat HDR so that the high temperature and geothermal energy is obtained. Then, the hot fluid is extracted via production wells. When the hot fluid is brought up to the surface, it is sent to the power plant to generate. Furthermore, the fluid after generation can be sent back to the injection wells to be re-heated and hence a closed loop is formed. When the power using to inject fluid is from the surplus power, it is called power to geothermal energy. It consists of two parts. First, the exceed power is used to drive cooling fluid into injection wells to exchange heat from HDR with higher temperature, during this period, the electricity is converted into geothermal energy. Second, hot fluid is transported to the power plant then electricity is converted into power. The concept of power to geothermal energy is favorable for the energy transition trend, however, there are still some fields need to be focused and researched, such as drilling process, creating fractures, the velocity and temperature of fluid for a good heat exchange and ground facilities management.

Over the past four decades, due to experience in oil and gas production, the technology to generate fractures hard rock and hard rock has been developed. Technical feasibility depends on the local conditions of the demonstration site. According to the degree of difficulty, the United States divides EGS development technologies into three categories: on-site EGS, near-field EGS, and undeveloped EGS. All early development projects such as Fenton Hill, Rosemanowes, Hijori, Fjällbacka and Ogachi Basel

are difficult greenfield EGS. As the hydraulic fracturing technology matures, the success rate of EGS gradually increases, such as Soultz, Habanero, Paranala, Insheim, Landau, Newberry, Desert Peak and Geysers. In addition to the development of mining technology, the early experience of EGS development also shows that EGS site selection is very important. For example, successful reservoirs are easier to develop in tensile stress environments (such as grab stone) than in compressive stress environments. In the following chapter, EGS pilot projects will be introduced.

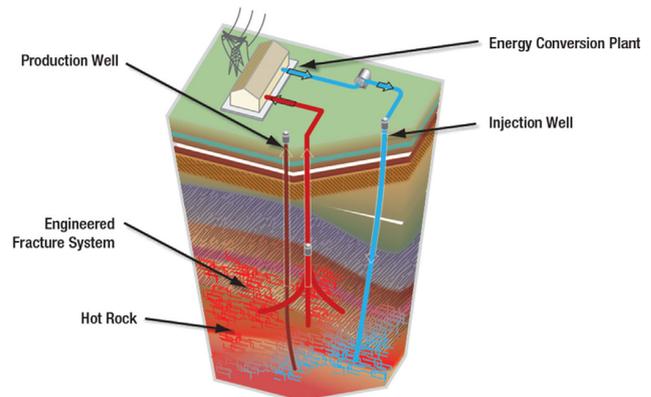


Figure 4. A concept of EGS Scheme

3.2 Pilot EGS Projects

3.2.1 Fenton Hill (1974-1995)

The first proposal of the use of geothermal energy generated at a great depth was posed at the Los Alamos Scientific Laboratory (LASL) in the USA in 1970. The concept of EGS was put forward first by the Los Alamos National Laboratory (LANL) in the USA. It was set out in a patent field in 1974 that describes the formation of an entirely natural tank designed to obtain geothermal energy. The venue for the project was around 40 km west of Los Alamos, west of the Río Grande (New Mexico). The task included creating a 4.4 km deep reservoir in granite with a temperature of 300 km and testing the 60kWe binary cycle power generation system operating at low and medium temperatures. However, due to the inability to achieve the expected capacity, the project was terminated. Although it was not possible to develop a commercial-grade EGS power plant at the Fenton Hill base, the project achieved the following important results:

- (1) The project verified the technical feasibility of drilling 5 km into hard rock.
- (2) The project confirmed that hydraulic fracturing technology can be used in low-permeability crystalline rock to create fractures with a total volume greater than

1 km³ for electricity generation.

(3) If the reservoir formations are in a compressive stress environment, continuous high-pressure reinjections are required to maintain the openings of the fractures. However, high pressure pumps consume the most power at the EGS site.

(4) Because the formation stress varies with depth, high-temperature downhole detection equipment should be developed to acquire data about the formation stress, fracture orientations, downhole temperature, flow rate, and pressure.

3.2.2 Rosemanowes (1977–1991)

Camborne Mining School conducted EGS testing in Rosemanowes, Cornwall, UK, with a potential of approximately 3 GWe. The on-site development goal is to maintain a capacity of 50–100 kg/s, 5 years of use time and no reduction in temperature. However, the reservoir is mainly controlled by natural fractures, so it is almost impossible to produce artificial fractures through hydraulic fracturing. The loss of circulating fluid on site exceeds 70%. In addition, due to high hydraulic impedance and short circuit, the goal could not be reached, Rosemanowes ceased operations in 1991. Recently, using the results of Rosemanowes EGS, the UK has developed a 50MWe commercial-scale EGS power plant in Eden in the same region. In addition, a commercial-scale EGS is planned to be built in the small town of Redruth in Cornwall, which will be put into production in 2015 and can generate 10MWe of electricity and 550MWt of heat.

3.2.3 Hijiori (1981–1986)

The geological conditions of Hijiori EGS are similar to Fenton Hill. Both locations are volcanic geothermal fields. Hijiori EGS is conducted by the Japan New Energy and Industrial Technology Development Organization (NEDO) and is Japan's first EGS test site. A 130kWe binary cycle power plant is used to generate electricity. Although the maximum temperature in the fracture area of 1800 m depth is 250°C, even if the distance between the injection well and the production well is only about 50 m, the loss of circulating fluid still exceeds 70%. Due to various factors, including fluid loss and reservoir fouling, Hijiori EGS was unable to achieve the expected target, so the test was terminated. Important information obtained through Hijiori EGS test:

(1) Because natural fractures already exist in the two wells, even if hydraulic fracturing will enhance connectivity, a short circuit may occur during heating. Therefore,

underground sealing should be used to prevent undesirable fractures.

(2) At that time, it was still difficult to predict the fracture direction or stress field. However, underground microseismic arrays should be used to monitor and/or identify the development of artificial fractures.

(3) Fenton Hill and Hijiori are located near the crater. If shallow wells are drilled in this type of EGS, high temperature fluids and lower power generation costs can be obtained.

3.2.4 Fjällbacka (1984–1989)

Fjällbacka EGS is located in western Sweden. The goal is to develop EGS as a greenhouse heat pump. The plan was implemented from 1984 to 1989. The hydraulic fracturing test used two wells with a depth of about 500 m. The horizontal distance between the two wells is about 100 m. Water was injected through the reinjection well at a temperature of 7°C, an injection pressure of 5 MPa and a flow rate of 1.8 kg/s. The hot water is then discharged from the production well at a temperature of approximately 16°C and a flow rate of approximately 0.9 kg/s. Despite the small distance between the two wells, the loss of circulating water is still about 50%, so the site is not economical.

3.2.5 Ogachi (1989–2001)

The second EGS project in Japan was carried out at the Ogachi plant near Yamabushi. The temperature at a depth of 1000 m exceeds 230°C. Under the supervision of the Central Electric Power Research Institute (CRIEPI), undeveloped EGS experiments and CO₂ isolation tests were conducted at the Ogachi EGS site. However, due to the loss of up to 75–90% of the circulating fluid in the field during the test, Ogachi EGS could not reach the level of commercial operation. The important results of Ogachi EGS are the same as those of the above EGS site. Due to the complex underground geological conditions, it is difficult to predict the direction of fractures before drilling. Downhole geophysical exploration is still needed to understand the stress distribution and fracture development in the well.

3.2.6 Basel (2005–2006)

Basel's EGS site is a project of the "Deep Geothermal Drilling Program" implemented by Geopower Basel. The goal of the project is to develop commercial-grade EGS power plants and heat pumps. The site is located in Basel and has a population of over 700,000. Basel is the third largest city in Switzerland and the hub of the European

pharmaceutical and chemical industries. In 2006, a hydraulic fracturing test was carried out in the granite layer at the EGS site in Basel, with a depth of approximately 5000 m and a temperature of approximately 200°C. The test caused thousands of micro-earthquakes. Due to the rapid increase in seismic activity, the hydraulic fracturing test was stopped. However, a few hours after the injection stopped, a magnitude 3.4 earthquake occurred and damaged the local structure. As a result, the plan was terminated, and local residents were compensated for their losses. Whether the impact was caused by the EGS project is questioned. Due to the Basel EGS case, the European Commission created a geothermal engineering integrated mitigation of reservoir induced earthquakes (GEISER) to standardize the development of EGS.

3.3 Exiting EGS Projects

3.3.1 EGS projects in EU

3.3.1.1 Soultz

Soultz EGS is the world's first commercial-scale EGS power plant. The production capacity has reached 25 kg/s, and the plant currently provides continuous hydrothermal power generation. The Soultz website is led by the European Commission. From 1997 to 1998, when commercial production was realized, the management of Soultz EGS was transferred to private companies such as Shell and several French and German companies. The important results of Soultz EGS are:

(1) Soultz EGS is an artificial fracturing reservoir that has been successfully used as a commercial-scale geothermal power plant. Site characteristics (such as natural cracks and their connectivity) are the main factors for the success of this EGS.

(2) The reservoir maintenance at this location is mainly affected by scaling. In order to reduce the skin-gathering effect in the well, acid leaching treatment was performed on this part to keep the reservoir fractures.

(3) The program adds a submersible pump to increase production and reduce reinjection pressure.

(4) High temperature of underground detectors. There is an urgent need to develop high-temperature materials and system designs.

3.3.1.2 Landau and Insheim

Since most geothermal reservoirs in Germany are low-temperature reservoirs, geothermal power generation applications are concentrated on EGS, while shallow low-temperature applications are concentrated on heat pumps. The German leading EGS geothermal power plants Insheim and Landau are located in the Upper Rhinegraben region of Germany, and their lithology is

almost the same as that of Soultz in France. The lithology of all artificial oil reservoirs is granite. Although the microseisms were caused by hydraulic fracturing on site, the degree of damage was still within acceptable limits. After completing about 150 geothermal projects, Germany successfully proved the commercial feasibility of greenfield EGS and related activities, such as transportation regulations. By 2020, the total capacity will reach 280 MWe.

3.3.1.3 Groß Schönebeck

The GroßSchönebeck test site is located 50 kilometers north of Berlin, Germany. The geothermal resource potential of this field is about 10MWe. The development of GroßSchönebeckEGS is led by the German Geoscience Research Center (GFZ, GeoForschungsZentrum Potsdam). The EGS well at the site is an old natural gas exploration well drilled in 1990 and a 150°C geothermal well drilled in 2006. The maximum horizontal distance between the production layers of these two wells is about 500 m. GFZ carried out site planning and installation in 2001. In 2003, a hydraulic fracturing test was performed on the old well, and the injection well was deepened to 4309 m, and the fracture channel of the old well was added. In 2004, a long-term reinjection test was conducted, and the hydraulic conditions of the reservoir were evaluated. In 2006, 8 months of geothermal well steering drilling was performed at a depth of 4440 m. The second hydraulic fracturing test was conducted in 2007. Depending on the thermal fluid conditions that can be produced, several binary cycle power generation units (500 kWe, 350 kWe and 150 kWe) were installed at the Groß Schönebeck site.

3.3.2 EGS projects in Australia

3.3.2.1 Habanero (Cooper Basin)

Habanero EGS was developed by Geodynamics Limited (GDY) in a resource collectively known as Innamincka granite. Much of the work is at the Habanero location, where four wells ranging from 4,205 m to 4,420 m were drilled near the early oil well McLeod 1 (McL). Naturally cracked granite is saturated with water and insulated by an overlying sedimentary layer of approximately 3,650 m. The EGS reservoir in this granite is limited to the critical low-angle sub-horizontal fault zone, that is, the Habanero fault that is easy to slip off. GDY recently demonstrated the technical feasibility of EGS in Habanero after completing the Habanero pilot plant project in October 2013. This work outlines the first numerical reservoir model established for the Habanese using the TOUGH2 thermodynamic simulator.

In 2003, Habanero 1 (H01) was hydraulically stimu-

lated, resulting in 28,000 seismic events within an approximately planar seismic cloud. The well was re-stimulated in 2005, adding a further 16,000 events and extending the seismic cloud. In November 2012, stimulation was conducted at Habanero 4 (H04) with the intent to expand the existing reservoir and to gain a better understanding of the geothermal system. Over 36 ML of water was injected and over 27,000 events were recorded.

The Cooper Basin is located in Adelaide in northern South Australia, close to Queensland. The goal of the project is to develop successful EGS in homogeneous granite and construct a binary cycle power generation system of approximately 100 MWe. Granite in southern Australia contains a lot of radioactive elements (such as uranium), which results in many shallow local high-temperature reservoirs. Geodynamics deepened the Habanero 1 injection well (depth 4421 m) from the original oil exploration well in 2003. The granite is under overpressure (35 MPa). Frequent drilling and industrial safety issues have delayed development. 1 The MWe EGS power plant was put into operation on site in early May 2013, followed by the 40 MWe power plant in 2015. The ultimate goal is a total of 450 MWe.

3.3.2.2 Paralana

The Paralana Geothermal Project is located about 600 km north of the city of Adelaide in South Australia in the Lake Frome Embayment east of the Mt Painter Inlier. Mesoproterozoic granitoids and gneisses of the Mt Painter Inlier can contain anomalously elevated U and Th contents resulting in high to very high heat production rates by global standards. Average heat production in the Mt Painter Inlier is $10 \mu\text{Wm}^{-3}$, which is around 4 times the rate of average granite and individual granites such as the Yerila Granite yield up to $62 \mu\text{Wm}^{-3}$. The Paralana project is exploring for viable EGS resources within the adjacent Poontana Graben where the Mt Painter basement rocks are overlain by a thick sequence of flat-lying Neoproterozoic, Cambrian and Tertiary sediments.

Petratherm (PTR) also adopted a strategy to collect mid-depth ultra-fine-line drilling to collect data about the project area before committing to drilling wells that reach reservoir depth. The preliminary results of the data well Paralana 1BDW1 are encouraging. In 2009, Paralana 2 was drilled to 4003 m and the temperature is expected to be about 180 – 200°C. The well is designed as a potential injection well, but instead of repeating the previous EGS project's strategy for hydraulic stimulation in long open-hole completions, it is better to fully casing and selectively perforate Paralana 2 to achieve multi-stage stimulation. Ok. The well is perpendicular to approximately 3400 m, below which the system deviates to 17°. During

drilling between 3670 and 3864 m depth, multiple unstable regions intersect with overfilled fluid-filled fractures, indicating widespread fracturing in deeper rock masses. The shut-off pressure indicates an overpressure of ~3300 psi. Weigh the slurry to 13.2 ppg to control the flow. As a result, the well can only be cased up to 3,725 m. The calculated bottom hole temperature at this depth is 190°C. By applying heat exchangers in the heat insulation layer (HEWI) mode, hydraulic fracturing and heat exchange are performed at the interface between the sedimentary rock layer and granite. The thermal insulation layer is shallow, and most of it is composed of sedimentary rock with low mechanical strength. In this type of geothermal site, it is easy to successfully create artificial cracks, so the cost and risk are low. This technology has been successfully used in petroleum reservoir engineering. Therefore, the engineering cost is lower than that using granite as the heat exchange rock. Currently, the production flow rate at the EGS site in Paraná is about 21.6 tons/hour and the fluid temperature is about 171°C. Petratherm plans to complete the third well including drilling, hydraulic fracturing and fluid circulation in 2014, and plans to build a 3.5 MWe binary cycle power plant in 2015.

3.3.2.3 Other EGS projects in Australia

Green Rock Energy has four EGS sites in southern Australia and one EGS site in western Australia. The largest site of EGS is the Olympic Dam in southern Australia, and it is expected that a 400 MWe EGS power plant will be built by 2020. The Raya Group has three EGS sites, two of which are located in the Otway Basin and one in the Cooper Basin. Geothermal Resources has two EGS sites, and Torrens Energy EGS has two EGS sites and is currently in the verification drilling phase. KUTh Energy has two EGS sites and is currently in the exploration and drilling stage. Greenerth Energy has EGS and oil extraction at two locations, and the demonstration plant is currently in the planning stage. Hot rock has 5 EGS sites in the Otway Basin and is currently in the stage of verification well drilling.

3.3.3 EGS projects in Asia

At present, the largest EGS development project in Asia is the Pohang project in South Korea. The EGS research project started in 2010 and is expected to build a 1.5 MWe EGS power plant in 2015. The reservoir lithology is granodiorite with a depth of 5 km and a temperature of 180°C. Pohang EGS will become the first MWe-level EGS power plant in Asia.

3.3.4 EGS Projects in USA

3.3.4.1 Newberry EGS Project

The Newberry EGS site is a volcanic geothermal field

with granite reservoirs and an undeveloped oasis EGS with high development difficulties. The Newbury Reservoir is located at a depth of 3067 m and the temperature is 331°C. The development goal for 2013-2014 is to complete two production wells. The site was developed by AltaRock Energy. The development tasks are divided between the cooperation teams as follows:

(1) Oregon State University (OSU) and National Energy Technology Laboratory (NETL) are responsible for the new reservoir 4D monitoring technology;

(2) The University of Oklahoma (OkU) is responsible for establishing EGS micro-seismic (MEQ) simulation technology based on geological and in-situ stress and statistical viewpoints;

(3) The Institute of Energy and Earth Sciences (EGI) at the University of Utah (UU) is responsible for novel crack tracking and evolution technologies;

(4) Davenport Holdings is responsible for new mining technologies;

(5) WLA-Fugro is responsible for 3D velocity imaging

(6) Lawrence Livermore National Laboratory (LLNL) is responsible for selecting drilling locations. The total capital required to develop the Newberry EGS site is \$43.8 million, of which \$21.4 million is subsidized by the Department of Energy (DOE) grant.

The main technology of the site is the use of thermally degradable strip insulation (TZIM) for hydraulic fracturing without the need for traditional closure methods to minimize drilling time. The AltaStim™ hydraulic shear model predicts possible electric shocks and risks. In addition, the structure of the 14-stage electric high-pressure centrifugal pump allows injection at 1000 gpm at 2000 psi. Other facilities include 15 microseismic monitoring stations, 8 borehole geophones, 7 ground geophones and a powerful monitoring station. A reservoir with an area of 1.5 km×0.7 km was successfully created, with a total reserve of about 1.5 -3 km and an injection index of about 2 kg/s/MPa. Overall, excellent artificial cracks were created at the site.

3.3.4.2 Geysers EGS Project

Geyser is a traditional geothermal field, with the world's largest geothermal installed capacity, with a total of 22 geothermal power plants. Calpine owns 19 companies. Calpine is responsible for the development of the EGS site in the northwest of the field, where existing geothermal wells with insufficient capacity are being developed as near-field EGS. The 20th geothermal power plant will be a 5 MWe EGS power plant. The site used metamorphic sandstone reservoirs at a depth of 3396 m and a temperature of 280°C. At present, the P-32 water injection well that has caused artificial cracks has been completed.

PS-31 production wells continuously produce high-quality hydrothermal steam. Lawrence Berkeley National Laboratory (LBNL) is a member of the Geysers EGS development team and is responsible for:

(1) Evaluation of fracturing technology;

(2) Combining InSAR surface deformation research and geomechanical simulation to conduct injection-induced earthquake research;

(3) Install at least 14 MEQ monitoring stations;

(4) Establish a tourism center as an EGS education exhibition and public communication space.

The important features of the EGS project are:

(1) After treatment, the urban sewage is pumped to the top of the hills, and then injected into the low-permeability stratum with a temperature of 400°C using a gravity head;

(2) Without using a large pressure pump, the cold fracturing method successfully produced artificial cracks around the wellbore due to thermal effects, thereby reducing vibration and energy consumption of the pump. As a result, the largest earthquake was less than M2.87;

(3) Hydrogen and oxygen isotopes are used to determine whether the produced water reacts with the geochemical reaction with the rock layer, and the results can be used to determine the flow path of reinjection;

(4) Since the development of this EGS site involves the transformation of existing oil wells, the development cost is low. Total funding is approximately \$133.3 million, of which \$6.2 million is subsidized by the US Department of Energy grant.

3.3.4.3 Raft EGS Project

The University of Utah is responsible for the Raft River EGS project. There is a traditional geothermal power plant of about 12MWe near the site, for which 4 production wells and 3 reinjection wells were drilled to achieve a total production flow rate of 315 kg/s. The EGS site has been planned since 2008 and already has four observation wells to measure earthquakes. The RRG-9 ST-1 well is 1,800 m deep and was completed by hydraulic fracturing in 2013. It is essentially a near-field EGS with moderate development difficulty. The reservoir lithology at the Raft River EGS site is granite with a temperature of approximately 150°C. In the process of hydraulic fracturing, 60°C of water is injected, followed by the cold fracture method, which involves injecting 13°C of water into the reservoir to create fractures around the well. Finally, 50,400–347,000 pounds of 20/40 and 100 mesh silica sand were used to generate reservoir fractures. The characteristics of this EGS project development are:

(1) Combined with the technology developed by the

US research team, such as the “cold crack hydraulic fracturing simulation” of the Idaho National Laboratory (INL), the impact events caused by the hydraulic fracturing process were simulated and predicted;

(2) LBNL conducted MEQ, downhole temperature distribution measurement, distributed temperature sensing system (DTS), inert gas monitoring and resistivity measurement;

(3) Measurements of underground telescopes are carried out by Sandia National Laboratory (SNL);

(4) Freight testing is performed by EGI.

The development goal of the Raft River EGS project is to operate a 5MWe EGS power plant, and by 2020, the continuous production flow rate of each well will be at least 20 kg/s. The funding required for this site is US\$ 10.6 million, of which US\$ 7.4 million is provided by the US Department of Energy grant subsidies.

3.3.4.4 Desert Peak EGS Project

ORMAT Nevada Corporation (ORMAT) has shared costs and received funding from the United States Department of Energy (DOE) to study the technical and economic feasibility of establishing an artificial underground heat exchanger in the eastern desert peak geothermal field. 130 kilometers (80 miles). The ultimate goal of the project is to develop 2-5 MW EGS power generation from an independent binary power station provided by one well or three wells. Initially focused on well DP 23-1, a hot and tight hole about 2.5 kilometers (1.5 miles) east of the hydrothermal well being produced at Desert Peak, a system for the EGS potential of the area. The evaluation was completed in May 2004. The first stage of evaluation includes:

(1) analysis of existing geological data, including new petrologic analyses of samples from well DP 23-1 and a nearby core hole (35-13 TCH);

(2) review of previously collected geophysical data;

(3) mechanical testing of cores from 35-13 TCH (none are available from well DP 23-1);

(4) obtaining and evaluating a new wellbore image log in well DP 23-1 to determine stress field orientation and evaluate the intrinsic fracture population;

(5) conducting an injection test of well DP 23-1 to determine baseline (pre-stimulation) well and reservoir characteristics;

(6) developing a conceptual model of the EGS portion of the field;

(7) numerical modeling of heat recovery to develop generation forecasts for various well configurations over a range of stimulated volumes;

(8) designing and conducting a “mini-frac” in well DP 23-1 to determine the magnitude of the least principal

stress;

(9) re-completing well DP 23-1 in preparation for hydraulic stimulation;

(10) preparation of a detailed plan to guide the next activities at the field (Phase II).

3.3.4.5 Bradys Hot Spring EGS Project

The Bradys Hot Spring Geothermal Field is the second field EGS site owned by Ormat, 7 km from the Desert Peak Geothermal Field. Using the existing 15-12 ST-1 geothermal wells, hydraulic fracturing was performed on the site in 2013 to establish a rhyolite geothermal reservoir with a temperature of 204°C. The purpose of the project is to increase the power generation capacity of each well to 2-3MWe, use self-supporting shear hydraulic fracturing technology, and use the site as a training base for the development and application of “EGS Toolbox” technology, which can be transferred to Other EGS projects. The development tasks of this EGS project are divided according to the cooperation team as follows:

(1) Ormat is responsible for the overall planning;

(2) GeothermEx is responsible for technical management, hydraulic fracturing facilities and simulation;

(3) The University of Nevada Reno (UNR) is responsible for the development of three-dimensional geological models and surface stress indexes;

(4) USGS is responsible for stress field analysis and construction simulation conducted with Temple University;

(5) EGI is responsible for tracer testing and geological modeling;

(6) Schlumberger’s Terra Tek is responsible for the formation and Core analysis

(7) GeoMechanics International is responsible for failure analysis and planning of hydraulic fracturing;

(8) LBNL is responsible for impact monitoring and analysis;

(9) Hi-Q geophysics is responsible for data collection and ground vibration interpretation;

(10) LANL and NETL are responsible for the EGS fracture network Imaging and simulation;

(11) SNL is responsible for the measurement of underground TV viewers.

The development funding of this EGS site is approximately \$6.6 million, of which \$3.4 million is subsidized by grants from the US DOE.

4. Simulation Methods of EGS

It is important to establish a framework to discuss and determine the common characteristics of EGS reservoirs that are critical to successful operation. The general con-

cept is a reservoir system consisting of porous media, usually with a natural fracture network, which may be intersected by high-conductivity, hydraulically induced artificial fractures. Flow mainly occurs in fractures and depends on the fracture pores, which may be a function of fluid pressure and thermal contraction in adjacent rocks. In the EGS system, the main challenges are to increase the permeability by enhancing natural cracks or forming artificial cracks, and to optimize heat recovery by injection. The heat is removed by injection fluid through the fracture system. On the premise that the behavior of the enhanced geothermal system (EGS) will be dominated by fracture flow, this article reviews the special functions required by any actual EGS numerical simulator. In addition to the basic functions of conventional geothermal simulators (that is, the ability to handle two-phase fluid flow in porous media and fracturing media, heat transfer and tracer transport), the following functions are also required: clearly indicating cracks, effective crack width Changes in stress and shear force, thermoelastic effects, the relationship between fracture pore size and electrical conductivity, and the passage of fluid flow in the fracture. The chemical reaction between water and rock and the coupling of reservoir model and wellbore model are also ideal characteristics. This article reviews the famous simulators that have been used or can be used to model EGS (TOUGH2, TETRAD, STAR, GEORCRACK, FEHM, FRACTure, GEOTH3D, and FRACSIM-3D) for the functions listed above.

About 70 projects participated in the experience of all HDR/HWR reservoirs (Rosemanowes, UK; Soultz-sous-Forêts, France; Hijiori, Japan; Fenton Hill, USA; and Ogachi-Akinomiya, Japan). Their experience and conclusions represent a large amount of accumulated knowledge related to EGS reservoirs. Based on their conclusions and our survey of geothermal developers and operators, we can list the necessary and ideal features to be included in the HDR simulator as follows:

- (1) explicit representation of the fractures;
- (2) fracture opening as a function of effective stress;
- (3) shear deformation and associated jacking of the fractures;
- (4) a relationship between fracture aperture and fracture conductivity, including the potential for turbulent flow in the fractures;
- (5) “channeling,” and thermo-elastic effects;
- (6) mineral deposition and dissolution;
- (7) a tracer module;
- (8) two-phase flow and the consequent complexities of phase change, relative permeabilities, capillary pressure effects etc.

4.1 Software Introduction

4.1.1 FRACTure

FRACTure is a finite element code for discrete fractures, used to simulate the coupling of hydraulic, thermal and mechanical behavior of fractured media. The model represents fluid flow through a permeable rock matrix and discrete fractures. The fluid flow can be modeled using Darcian and turbulence control equations. Thermoelastic and porous elastic effects are applied to porous media, and the crack opening is nonlinearly related to rock stress. Heat transfer includes conduction in rocks and transmission in fluids, and is coupled to elasticity and pyrolysis through thermal expansion and nonlinear constitutive relations. FRACTure has been used to model various geological problems, including: transportation to buildings, space heating, tracer propagation, non-layered hydraulic behavior at Soultz, and heat extraction during aquifer utilization. It has also been used to compare the simulation of HDR reservoirs using 2D and 3D single fractures and multiple fractures. It has been used to model Soultz HDR reservoirs using flow and turbulence models in major fractures. FRACTure’s methods and concepts make it suitable for analysis of various reservoir operations. Its advantage is that the physical range has been achieved through three-dimensional hydraulic, thermal and mechanical coupling. It does not include the coupling of two-phase flow or geochemistry and flow. Channels are not directly supported, but can be modeled using the material properties of different crack elements. No coupling between fracture shear displacement and aperture.

4.1.2 GEOTH3D

The GEOTH3D simulator by Yamamoto et al. use microseismic data as a guide for permeability distribution and have applied it to Hijiori, Ogachi and Fenton Hill reservoirs. GEOTH3D uses 3D finite difference approximation to solve mass and energy balance according to Darcy’s law. The model can describe the water and heat transfer in porous media. When applied to geothermal reservoirs, the available microseismic data will be used to define non-uniform porosity proportional to the microseismic intensity. Therefore, the flow rate in the reservoir area with the strongest microseismic activity during stimulation is greater. GEOTH3D is attractive for modeling non-uniform porous media using microseismic data obtained during stimulation. The model does not include discrete cracks. In general, porous media models tend to be optimistic in terms of energy production. This is because porous media models often cannot capture the sharp local temperature

gradients and cooling that may occur in cracks, and cannot represent pore size changes due to stress or thermoelastic effects.

4.1.3 FRACSIM-3D

FRACSIM-3D codes (including fracture network models of fluid flow and heat transfer) have been used to model the Hijiori and Soultz reservoirs. As described by Jing, the model is an extension of the 2-D fracture simulator FRACSIM-2D. Tezuka and others have developed similar models. The model focuses on the following reservoir effects: 1) fracture shear and expansion during stimulation and circulation; 2) thermoelasticity during circulation; 3) chemical dissolution and precipitation during circulation. FRACSIM-3D can be used to analyze stimulation and reservoir testing operations, including tracer analysis and simple chemical dissolution models. In the Hijiori model, the correlation between the amount of microseism and the predicted simulation is very good. Then perform statistical flow calculation. Depending on the distribution of the fractures produced, different flow rates are obtained between the injection well and the production well. However, the average value of these holes is very consistent with the observed flow rate. The tracker calculation also obtained a good match. Then, the best-fit flow and tracer models were used to predict reservoir behavior during the 30-day test period and during long-term production and injection. Once developed, FRACSIM-3D can analyze both reservoir enhancement (well stimulation) and reservoir operation. Stimulation analysis seems to be very powerful, including shear expansion (based on a single bulk stress). The reported stimulus results show a good correlation with the observed microseismic data. However, there has been active debate about the exact meaning of micro-earthquake events, especially in Hijiori, where the best connection to the fault system occurs in areas of relative earthquake. FRACSIM-3D draws cracks to form an uneven porous media model. Inevitably, this will lead to tailing of local gradients near fractures and may lead to optimistic predictions of reservoir life. Including simple chemical dissolution and deposition are useful functions.

4.1.4 Geocrack2D

Geocrack2D is a finite-element-based simulator developed by Swenson and Hardeman that focuses on flow in fractures and has been used to model the Fenton Hill and Hijiori reservoirs. The code can solve coupled thermal, hydraulic and mechanical problems where the flow is in fractures. A Geocrack2D model consists of rock blocks with nonlinear contact and discrete fluid paths between

the blocks. Heat transfer occurs by conduction in the rock blocks and transport in the fluid. A tracer model is also included that uses particle tracking with thermal decay, diffusion, and adsorption of the tracer. The user interactively defines the finite-element mesh, the material properties, boundary conditions, and solution controls. Geocrack2D's discrete-fracture approach is similar to that used in FRACTure. The fracture aperture is a function of effective stress, flow is calculated using the cubic law, thermo-elastic effects are included in the model, and tracers are calculated using a particle-tracking algorithm. The model does not include coupling of fracture aperture to shear displacement, and there is no porous-medium flow. The program is interactive, with graphical feedback to the user in all phases. At the present time the implementation is 2-D; however, a three-dimensional version is under development.

4.1.5 TOUGH2

TOUGH2 is a general-purpose numerical simulation program for multi-phase, multi-component fluid and heat flow in porous and fractured media developed at Lawrence Berkeley National Laboratory of the U.S. TOUGH2 allows simulation of 1-D, 2-D and 3-D geometry of porous or fracture media. The heat and mass transfer processes are completely coupled. The transport of tracers with adsorption and radioactive decay is illustrated. The treatment of natural gas in the regulations is extensive, including all the major gases normally found in geothermal reservoirs. For dissolved solids, including the effect of NaCl precipitation and dissolution on porosity and permeability. One of TOUGH2's more important features is the multiple interactive continuity or "MINC" method. In EGS or HDR systems, there is usually a high temperature gradient between the matrix rock and the circulating fluid. MINC can distribute the rock matrix in order, so it can simulate the pressure and temperature transients between the matrix rock and the injected fluid. TOUGH2 allows irregular grid heights, so discrete cracks can be easily handled. When using an irregular grid, care must be taken because the accuracy of the solution depends on the accuracy of the various interface parameters in the flux equation that can be represented by the average condition in the grid block. A prototype interface between TOUGH2 and Golder Associates' FracMan discrete crack generator has been developed. No consideration is given to flow channel effects and discrete fracture pore size changes due to stress or thermoelastic effects. The compressibility and expansion coefficient constants of rock are used to simulate the influence of pressure and temperature on porosity and permeability. The space discretization is made direct-

ly from the integral form of the governing equations. This method avoids any reference to a global system of coordinates and allows irregular discretization of the considered domain.

4.1.6 TETRAD

The TETRAD simulator developed by the Calgary Computer Modeling Group in Alberta, Canada is a finite-difference numerical simulator that has been widely used in the simulation of hydrothermal, oil, and natural gas reservoirs. Conservation equations are expressed in the form of traditional differential equations and then discretized. These equations are fully coupled, and the simulator can be used to simulate one-dimensional, two-dimensional, and 3-D heat and mass flow in porous or fracturing media. The fracture can be specified by using the dual porosity/permeability option. It is assumed that each matrix or crack block is in local thermodynamic equilibrium. The Warren and Root formula is used to describe the interaction between the matrix and the crack. The simulator allows selective zoning of the considered reservoir area by using the “Local Mesh Refinement” option. This function allows partitioning of various parts of the basic grid, so that the selected part of the simulation area has a higher grid block resolution. However, this local mesh refinement method is not similar to the MINC method used in TOUGH2 and cannot be used to model pressure and temperature transients within the matrix block. TETRAD contains all the functions required for reservoir research. The unresponsive tracking package is comprehensive. Discrete cracks can be simulated, but does not include pore size changes due to stress or thermoelastic effects. The flow channel effect is not considered. The documentation is very rich, and TETRAD is considered to be one of the more user-friendly simulators in the industry.

4.1.7 STAR

The STAR simulator developed by Maxwell Technologies in San Diego, California has been used for hydrothermal, oil and gas reservoir simulation (including heavy oil thermal recovery). In the discretization of the governing equation, a finite difference scheme is adopted. It is a one-dimensional, two-dimensional or 3-D simulator that contains all the functions commonly found in hydrothermal reservoir simulators, including tracer modules, NaCl deposition and dissolution, and non-condensable gases. The standard processing method for rock compaction includes using a user-specified rock compressibility factor in the simulator. Changes in pressure and temperature lead to changes in rock porosity and permeability. STAR has

been used for simulation studies in hydrothermal, natural gas and heavy oil thermal recovery projects. This is a typical reservoir simulator with all the necessary functions for hydrothermal reservoir simulation studies. The “Permeable Matrix” option can be used to simulate pressure and temperature transients between fractures placed in a rectangular grid system and matrix rock. The simulator includes a comprehensive non-reaction tracking package. Did not consider the effect of fluid channel, nor the effect of stress on fracture pore size.

4.1.8 FEHM

The FEHM (Finite Element Heat and Mass Transfer) developed by Los Alamos National Laboratory has been used to simulate hydrothermal fluids, oil and gas reservoirs, nuclear waste separation, groundwater modeling, and HDR reservoirs at Fenton Hill Reservoir. It simulates non-isothermal, multiphase, and multicomponent flow in porous media. Using the controlled volume finite element method, the heat and mass transfer equations of multiphase flow in porous media and permeable media are solved. The permeability and porosity of the medium depend on pressure and temperature. The specification also specifies the mobile air and water phases and uncoupled tracers (e.g. tracer solutions that do not affect heat and mass transfer solutions). The tracer can be passive or active. FEHM can simulate 2D, 2D radial or 3D geometry. Using double porosity/double permeability models or double porosity models, FEHM can simulate the flow controlled by fractures and fault flows in many areas. The code can handle coupled heat and mass transfer effects, such as boiling, drying, and condensation, and can incorporate various adsorption mechanisms, from simple linear relationships to nonlinear isotherms. FEHM is a powerful two-phase porous media model with good traceability and multiple reaction tracers. The formula is rigorous and well documented and has undergone extensive verification. FEHM can model the motion of water and steam phases and thermal motion through convection and conduction, making it very suitable for EGS simulations. FEHM combines 3-D volume elements with 2-D flat elements to allow integration with discrete fracture network (DFN) generators. The 3-D version (official release) does not include elastic deformation, discrete fractures or pore size changes due to stress or thermoelastic effects. These are only included in the 2-D version and are not widely used. A prototype interface between FEHM and Golder Associates’ FracMan discrete crack network generator has been developed. FEHM does not provide mechanical coupling, but has a tracer test modeling interface, which is helpful for model calibration.

Table 1. Comparison for different software

Capability	FRACture	GeoTH3D	FRAC-SIM-3D	GEOCRACK
Discrete fractures	√		√	√
Aperture function of normal stress	√		√	√
Aperture function of shear			√	
Flow rate as function of aperture	√			√
Channeling	√			√
Porous flow in matrix	√	√		√
Thermo-elastic effects	√		√	√
Tracer transport	√		√	√
Multi-Phase Flow				
3D	√	√	√	√
Irregular grid			√	
Mineral deposition/dissolution			√	
Capability	FEHM	STAR	TEDRAD	TOUGH2
Discrete fractures	√	√	√	√
Aperture function of normal stress				
Aperture function of shear				
Flow rate as function of aperture				
Channeling				
Porous flow in matrix	√	√	√	√
Thermo-elastic effects	√	√	√	√
Tracer transport	√	√	√	√
Multi-Phase Flow	√	√	√	√
3D	√	√	√	√
Irregular grid	√			√
Mineral deposition/dissolution				√

4.2 Literatures of Simulation Development

At present, numerical simulation is the main tool for studying EGS systems. Initially carried out HDR (hot dry rock) exploration, HDR volume and grade evaluation, the construction of artificial geothermal reservoirs and heat exchange and transportation research. Huang et al. Based on the data from the HDR site of the Songliao Basin in China, the heat extraction process of fractured reservoirs

was numerically simulated and the main parameter changes in the next 30 years were predicted. Chen et al. The long-term operation process of EGS system under different geological conditions is predicted by the numerical model developed by us. Song et al. CO₂ was used instead of water as the working fluid in the studied EGS. Wang and Zhang introduced the fracture network simulation method in the analysis of hydraulic fracturing and studied different conceptual models of EGS fracture flow. Due to induced earthquakes, the development of many new deep geothermal technologies (such as the Enhanced Geothermal System (EGS)) has slowed. The advanced traffic signal system can timely evaluate the efficiency of the implemented stimulus strategy to make changes, which can help the successful development of EGS technology. Karvounis et al. proposes a hybrid model modeling method that combines numerical calculation with stochastic geomechanical modeling and can be used from such traffic lights. The hybrid model can help probabilistically assess the risk of induced earthquakes and the thermal energy gains that should be expected from the decided stimulus strategy.

When controlling the feasibility and feasibility of the enhanced geothermal system (EGS), the permeability structure generated by the high fluid pressure of geothermal resources is the most important parameter. Miller used a minimalist approach to modeling, and the results showed that all observations from the Basel (Switzerland) fluid injection experiment matched well with a simple model that controlled the main system. It is a large-scale change in permeability at the beginning. The excellent agreement between the observations of these and these simplest models suggests that these systems may not be as complex as envisioned, and therefore provide strategies for more complex future modeling to help constrain and utilize these systems. McClure and Horne used a discrete fracture network simulator to perform the calculation model, which couples the fluid flow to the stress caused by the fracture deformation. The modeling results show that several geological conditions must be passed to enable stimulation to occur only by inducing slippage on existing fractures, and to avoid significant opening of new or existing fractures. In Börner’s paper, virtual experiments can be used to optimize geophysical monitoring systems. Secondly, the 3D geological model is processed, meshed and used for finite element simulation research. Third, it shows the transient electromagnetic simulation results of a deep-enhanced geothermal system. Fourth, when using a borehole receiver, the detectable change in the measurement signal occurs by 25%. Börner concluded that the optimal positioning of the source and receiver requires

advanced simulation techniques. In Xu, a new method for modeling flow and heat transfer in a complex fracture model is proposed. Second, for larger physical scales and longer spans, there is computationally feasible modeling. Finally, the model verification of the industrial scale enhanced geothermal system reservoir is carried out.

The evolution of EGS requires a spatial and temporal permeability field. During the injection of non-isothermal fluids, thermoelastic stress and fluid pressure changes will act on partially opened or hydrothermally changed fracture groups to increase the formation permeability. The physical couplings that drive this behavior are non-linearly dependent on each other to varying degrees. To explore these interactions, we are developing a simulator that can use multiple methods to couple the main physical principles of shear stimulation, thereby allowing flexibility when using integral or interleaved numerical schemes. Numerical simulation has become a standard analysis tool for scientists and engineers to evaluate the potential and performance of EGS. Various numerical simulators developed by industry, universities, and national laboratories are currently available and have been used to understand EGS on site. White and Phillips summarized the initial combination of seven benchmark problems, described code comparison activities, provided example results of the problem, and recorded the function of currently available numerical simulation codes to indicate that they occurred during the production of geothermal resources coupling process.

Biagi et al. studied the simulation of using CO₂ as a working fluid to extract heat from geothermal reservoirs; the underground flow simulation uses a multiphase flow solver TOUGH2; developed an optimized code based on genetic algorithms for geothermal applications; and CO₂. The injection rate is optimized for constant mass and constant pressure injection. Gaucher et al. provides a comprehensive overview of existing methods suitable for geothermal environments. The overview outlines the advantages and disadvantages of different methods, points out the gaps we understand, and describes the requirements for geothermal observations. In the paper, most of the prediction methods are focused on the stimulation stage of the enhanced geothermal system that is most prone to seismic events.

4.3 Coupled Simulation Development

4.3.1 Thermal-Hydro Coupled Model

When cold water is injected into the reservoir and hot water is pumped out of the reservoir after receiving heat energy, a hot liquid flow occurs. In the thermo-hydro cou-

pling, the influence of deformation (the evolution of porosity/permeability due to fluid pressure and chemical reaction and the decoupling of deformation) can be ignored, but the fluid characteristics (such as viscosity, density, transmission, etc.) related to temperature and pressure (Thermal coefficient, etc.) can be ignored. The main control variables that determine the endothermic performance of the system are important geophysical processes, such as advection, dispersion, diffusion, delay, buoyancy, and regional surface flow. In TH coupling, a lot of research has been conducted on the operation of geothermal reservoirs and reservoir parameters. A significant number of studies have been done on operational and reservoir parameters of a geothermal reservoir in TH coupling. These studies are grouped according to the factors such as fracture spacing, reservoir heterogeneity, reservoir thermal gradient, reservoir fluid salinity, injection temperature, flow rate, injection fluid properties, areal flow and well spacing.

4.3.1.1 Fracture Spacing

Kolditz modeled the heat transfer process in fractured crystalline rocks when extracting heat from HDR reservoirs. He studied the effect of size on heat extraction and compared the results of the 2½-D model with the 3D model. In the 2½-dimensional model, only the 1-dimensional heat conduction in the rock matrix is considered. The results of the study show that after 20 years of production, the 2.5-D model overestimates the heat loss by as much as 11% compared to the 3-D model. Zeng et al. studied the heat extraction of granite reservoirs in the Yangbajing geothermal field. Based on geological data at a depth of 950-1350 m, the reservoir was modeled at a uniform temperature of 248°C (ignoring the geothermal gradient). They modeled the heat extraction process in the reservoir by considering horizontal wells (dual well system). The results showed that the reservoir maintained 3.23–3.48MW of electricity for 20 years, with an energy efficiency of approximately 17.16%-50%. Zeng et al. numerically simulated granite reservoirs by considering horizontal and vertical wells. They showed that compared to vertical wells, the horizontal well system increased water production and reduced reservoir impedance parameters. The analysis also showed that the horizontal well system was more efficient due to the presence of buoyancy and also reduced the pumping capacity. Guo et al. investigated the power generation potential of the Songliao Basin (North-east China). Use the TOUGH2-EOS1 code to perform 3-D coupled thermal fluid simulations. The changes of internal temperature and pressure of the reservoir under different mass flow rates and their effects on energy production were studied. Yu et al. applied the TOUGH-EGS code to study the thermal recovery potential in Yilan, Taiwan.

The parameters of different well distances were studied. The proposed model shows that the closer the distance between the water injection port and the production well, the faster the temperature drops, thereby reducing the heat absorption of the reservoir. Mudunuru et al. Use a reduced-order model to predict the thermal performance of the Fenton Mountain (second stage) geothermal reservoir. They concluded that the fracture zone permeability plays a major role in heat extraction. Few studies have undertaken reservoir stimulation measures to increase the reservoir's flow conductivity. Some past studies believe that there are multiple hydraulic fracturings in low permeability geothermal reservoirs. Multiple hydraulic fracturing provides more conductive flow paths and increases the surface area between the flowing fluid and the surrounding formation. Studies of multi-fractured reservoirs have shown that as the fracture spacing decreases and the number of reservoir fractures increases, the heat rejection performance also increases. Li et al. Through numerical simulation, by considering key sensitivity parameters (such as well spacing, lateral length, reservoir permeability and series of multi-fractured reservoirs), through numerical simulation, the mass flow is optimized, and the benefits are maximized Present value. Chen et al. consider randomly distributing fractures into 3-D low permeability reservoirs. Studies have shown that in larger fractured orifices, the fluid temperature in the production well decreases faster than in smaller fractured orifices. Shaik et al. studied the effects of mass flow and working fluid heat transfer coefficients in fractured geothermal reservoirs.

4.3.1.2 Reservoir Heterogeneity

The existence of spatial heterogeneity in the reservoir may cause water channeling and reduce the volume of the reservoir participating in the flow field. Huang et al. studied the effect of heterogeneity on thermal recovery performance and reservoir life. Vogt et al. studied the transient temperature and pressure of 400 sets of fault zones in a dual wellbore system to achieve heterogeneity in production wells. Their research shows that the distribution of porosity/permeability and thermal conductivity in the fault area greatly affects the heat rejection rate of the reservoir. Crooijmans et al. studied the effect of the phase heterogeneity (net-to-gross ratio, N/G) of geothermal dual structure under different operating conditions on life and energy production. In all groups of heterogeneous reservoirs, at lower N/G ratios, the temperature of the production wells decreases more slowly than higher N/G ratios. Willems et al. shows that if the well is placed parallel to the ancient flow direction, the pumping losses will be reduced. Hadgu et al. studied the effect of fracture orientation relative to the well-plane on the thermal recov-

ery performance of heterogeneous reservoirs. They show that the orientation of horizontal wells is more effective than the orientation of vertical wells inside the reservoir, and the temperature decreases more slowly. Kalinina et al. showed that heat extraction and temperature drop usually depend on the horizontal/vertical distribution of the permeability field and the fracture spacing. Cracks in granite and carbonate reservoirs usually exhibit a rough surface. Few researchers have numerically studied the effect of crack roughness and heterogeneity on flow field evolution and endothermic properties. Neuville et al. studied the effect of crack roughness on heat extraction. Their results indicate that the roughness of the fracture may be the cause of fluid channeling inside the reservoir and affecting heat extraction.

4.3.2 Thermo-Hydro-Chemical Coupled Model

The injection of cold water into the geothermal reservoir will enhance the water-rock reaction, which will initiate the dissolution/precipitation process, change the pore geometry of the reservoir, and thus its hydraulic and transport characteristics, such as porosity/permeability. Many studies have focused on the evolution of porosity/permeability affected by geochemistry during thermal extraction. In fact, the rate of permeability change caused by thermo-water-chemical processes depends on reservoir mineralogy and temperature, and injection conditions (e.g. mass flow rate, injection temperature). Jing et al. numerically studied the effect of initial rock temperature and permeability evolution on dry-hot granite reservoirs. In their study, a 3-D fracture network was simulated in an equivalent porous medium. The permeability is calculated based on the pore size of a single fracture. The increase in pore size is related to local temperature and fluid chemistry. They found that with the enhancement of the water-rock chemical interaction, the evolution of permeability is more significant at high reservoir temperatures. Kiryukhin et al. numerically simulated the hot water chemistry (THC) process of different geothermal reservoirs in Japan and Russia. They observed that the rate of decrease in porosity depends on the mineral composition of the reservoir, temperature, and flow conditions (mass flow, single-phase/two-phase). Rabemanana et al. Bächler and Kohl and André studied the evolution of porosity/permeability caused by the dissolution and precipitation of Soultz granite (ie calcite, dolomite, quartz, and pyrite) in the Soultz-sous-Forêts enhanced geothermal system. These results indicate that the increase in porosity/permeability near the injection well is mainly due to the dissolution of calcite. The reaction rate kinetics of other minerals (ie quartz and pyrite) are slower than calcite. In Pandey's paper, numeri-

cal simulations were conducted in fractured limestone reservoirs. The results show that the evolution of the fracture transmittance is sensitive to the injection temperature and the concentration of dissolved minerals in the injection water. In both saturated and undersaturated cases, due to rapid changes in reservoir solubility and reaction rate, the transmittance of fractures is not monotonous in time. They reported that the transmissivity evolution is faster at higher injection temperature than for lower injection temperature. In fact, in a carbonate reservoir, fracture heterogeneities have a minor role in flow channeling and their effects are insignificant in heat extraction. Research by Pandey et al. and Pandey and Chaudhuri show that the rapid reaction kinetics and retrograde solubility of calcite lead to very different flow patterns compared to silicate reservoirs. This indicates that the higher water-rock (especially calcite and slower dolomite) interactions in carbonates may create significant complexity in the heat extraction process. However, in granite reservoirs, injection of fresh water/unsaturated water at a lower injection temperature ($>70^{\circ}\text{C}$) will enhance the heat extraction and dissolution of minerals, resulting in a longer flow path.

4.3.3 Thermal-Hydro-Mechanical-Chemical (THMC) Simulation Models

Geothermal reservoir simulation can increase geothermal recovery efficiency by about 10% and provide data on drilling depth and location to reduce drilling costs. At present, the EGS numerical simulation including the thermal-water-mechanical-chemical (THMC) coupling process is not yet fully mature. The five EGS sites in the United States all use THMC simulation technology suitable for the site characteristics. Currently, there are twelve EGS simulation programs funded by grants from the US Department of Energy. The total expenditure is about 10.34 million US dollars, accounting for 17-27% of the total funds, which shows the importance of numerical simulation technology. Seven laboratories and institutions funded by the US Department of Energy are involved in the development of hydraulic fracturing simulation technologies, including PNNL, LANL, LBNL, Pennsylvania State University (PSU), OkU, Colorado School of Mines (CSM) and INL. Because geothermal reservoir simulation involves formation parameters, it is difficult to accurately quantify uncertainty. For example, the assumptions and numerical limits should be set according to the local reservoir environment. It is difficult to simulate all formation environments with one software, so there are many geothermal numerical simulation software packages, and it is difficult to quantitatively evaluate their advantages and disadvantages. After Stanford University evaluated

the thermal simulation software available worldwide in 1981, no new simulation software was evaluated for the next 32 years. Since geothermal development is based on local conditions, it is necessary to conduct a preliminary evaluation; therefore, it is important to choose the appropriate simulation software. PNNL compiled a database of software information and analyzed their functions to understand the advantages, disadvantages, and simulation accuracy of each numerical model.

The THMC simulation technology developed by LBNL mainly focuses on the cross-software integration of geochemical simulators, such as TOUGHREACT, ROCMECH and FLAC3D. The hydraulic fracturing simulation of Newbury EGS was performed using isotope measurements and TOUGHREACT/ROCMECH. The main body of the TOUGH EGS module was developed by CSM and is composed of resources from the LBNL TOUGH series and Computer Modeling Group Ltd. The mass and energy conservation equations of TOUGHESG are the same as those of TOUGH series, and all use the integral finite difference method. The mechanical equilibrium equation is based on the assumption of pore thermoelectricity, and the geomechanics module and the mass transfer module are fully coupled. For geochemical coupling, TOUGHREACT convergence issues and mechanical and mass/heat transfer modules have been improved simultaneously. For the fracture module, the geochemical reaction and mass/heat transfer between the fracture and the bedrock are processed through multiple continuous processes to adapt to the in-situ discrete fracture conditions. PSU developed a model that is capable of evaluating the shock that is caused by hydraulic fracturing. The model was verified at the Soultz, the Geysers, Cooper Basin and Newberry EGS sites. A relationship between the porosity-permeability and the fractured surface was defined in the model. In conjunction with TOUGHREACT and FLAC3D, a spatial permeability evolution mode was also added to improve the asynchronous disadvantage of the continuous mode of the coupled THMC. By considering the development of stress and fractures that are caused by the contact with microscopic particles as well as their permeability, the discontinuous mode is fit onto a cellular grid for the hydraulic fracture simulations.

5. Working Fluids

Early and current attempts to develop EGS in the United States, Japan, Europe and Australia all use water as a heat transfer carrier. As a heat carrier, water has many advantages, but it also has serious defects. A disadvantageous property of water is that it becomes a strong solvent for dissolving rock ore materials at high temperatures. After

the water is injected into the hot rock fissures, it produces a strong dissolution and precipitation effect, which changes the permeability of the fissures, which makes it difficult to operate the EGS in a stable manner. Water and carbon dioxide (CO₂) are popular working fluids, mainly discussed in EGS. Compared with the idea of using carbon dioxide, water has been used as a heat transfer fluid in several EGS projects. In view of the problems in the operation of EGS with water as a heat carrier, in recent years, scholars and related research institutions at home and abroad have conducted studies on the use of supercritical carbon dioxide as a circulating fluid to strengthen the geothermal system. This method can avoid a series of problems that may be caused by the injection of aqueous solution, while achieving the resource utilization of carbon dioxide, it can also be stored in the underground medium. This is of great significance to the reduction of carbon dioxide emissions and the utilization of renewable energy, and this field is showing broad application prospects.

5.1 Comparison with Water and CO₂

Brown initially proposed a CO₂-based enhanced geothermal system (CO₂-EGS), in which supercritical CO₂ is used as a working fluid that absorbs heat. The author points out the advantages of using CO₂ as a reservoir fluid for effective thermal recovery. Many studies have reported the importance of using supercritical CO₂ in reservoirs because of its high heat absorption rate, large expandability and compressibility. CO₂ fluid temperature changes will produce a high-density ratio, resulting in significant buoyancy, which reduces buoyancy. In addition, as global temperatures rise, people strongly encourage efforts to reduce carbon dioxide emissions, and the idea of using carbon dioxide as a working fluid in geothermal heat combined with the storage and thermal recovery of carbon dioxide has attracted researchers and industry. CO₂ is a non-polar solvent, which means that it has low salt solubility, which reduces the possibility of scaling and sedimentation in the wellbore and surface equipment, so there is no obvious mineral dissolution and precipitation in the enhanced geothermal system using CO₂ problem. However, Brown also pointed out that the lower heat capacity of CO₂ is not conducive to the effective exploitation of geothermal resources, but the faster CO₂ flow rate due to the lower viscosity of CO₂ can partially offset the adverse effects of heat capacity. Table 2 compares the advantages and disadvantages of CO₂ and water that can be used as heat transfer fluids in enhanced geothermal systems.

Table 2. Comparison between CO₂ and Water

Fluid characteristics	CO ₂	Water
Chemical characteristics	Non-polar solvent; weak solvent for rock minerals	Strong solvent for rock minerals
Fluid circulation characteristics in the wellbore	Greater compressibility and expansion, subject to greater buoyancy; with lower energy consumption, can maintain fluid circulation	Less compressibility; moderate swelling, less buoyancy; larger pumping equipment needed to provide energy to maintain fluid circulation
Fluid flow characteristics in the reservoir	Lower viscosity, lower density	Higher viscosity, higher density
Fluid heat transfer characteristics	Smaller specific heat capacity	Bigger specific heat capacity
Fluid loss characteristics	May contribute to the geological storage of greenhouse gases (CO ₂), and obtain certain economic benefits by reducing greenhouse gas emissions to offset part of the cost of thermal energy extraction	Water loss will increase engineering costs (especially in arid areas), hindering the geothermal development of reservoir

5.2 CO₂ as Working Fluid

In 2006, Pruess conducted a quantitative study on the characteristics of heat transfer and mass flow in a CO₂-enhanced geothermal system through simulation work for the first time. In addition, the simulation study also compared the differences between enhanced geothermal systems using CO₂ and water as heat transfer fluids under certain thermodynamic conditions. For the simulation of the CO₂ enhanced geothermal system, the study used a two-dimensional model. Because of the greater density difference between the hot fluid near the production well and the cold fluid near the injection well in CO₂-EGS compared to water-EGS, there will be a significant buoyancy effect. The simulation results show that under the same initial reservoir conditions (temperature 200 °C, pressure 50 MPa), the thermal recovery rate and mass flow rate of CO₂-EGS are significantly higher than that of water-EGS, which is because of the At lower temperatures (about 40 °C), the increase in water viscosity is more pronounced than CO₂, thereby enhancing the mobility of CO₂ near the injection well. Pruess also conducted a sensitivity study on the initial reservoir temperature (120, 160, 200, and 240°C, respectively). Sensitivity simulation results show that under low temperature conditions, the increase in thermal recovery rate is more obvious. This

simulation result also made us realize that the method of using CO₂ to extract geothermal resources can be applied not only to high-temperature geothermal systems, but also to low-temperature geothermal systems. In addition, the simulation results of the sensitivity to the injected CO₂ temperature and the initial reservoir pressure show that the increase of the injected CO₂ temperature (from 20 °C to 40 °C) gives CO₂-EGS an advantage over water-EGS in geothermal energy exploitation. Weakened, and the reduction of the initial reservoir pressure (from 50 MPa to 40 MPa) will make this advantage more obvious.

Based on the above research, Pruess studied the energy production of CO₂-EGS under different initial reservoir pressure conditions based on a two-dimensional model. The simulation results show that the initial reservoir pressure has no effect on water-EGS energy production, but has a significant effect on CO₂-EGS, and the latter's thermal recovery rate is significantly higher than the former. For CO₂-EGS, under different initial reservoir pressure conditions, the thermal recovery rate changes with time show some unique characteristics, because temperature and pressure will affect the fluid density and viscosity changes, and thus the mobility of CO₂ cause an impact. Based on the above simulation results, Pruess pointed out that in order to obtain a better geothermal production effect, it should be more feasible to set the production port of the production well at the top of the reservoir. This can prevent the cooled fluid from flowing directly into the bottom of the reservoir, thereby extending the flow path of the cooled fluid and helping to obtain more thermal energy from the reservoir. Further simulation results also confirmed the above conclusion.

In 2010, Atrens et al. used radiation instinct (the maximum work that can be done in a thermodynamic system from a given state to equilibrium with the surrounding medium) to represent the potential power generation capacity of different geothermal mining systems. However, it should be noted that in actual situations, due to the different thermodynamic characteristics of CO₂ and water in the production well, the surface power generation equipment used is also different, and the amount of power generation directly depends on the specific design of the surface equipment (such as CO₂-EGS may use a turbine, while water-EGS may use a double-circulation system). Their simulation results show that the exothermic instinct produced by CO₂-EGS is lower than that of water-EGS. The reasons are as follows: ① CO₂ has a lower heat capacity than water, so a larger CO₂ flow rate is required to maintain an approximate thermal recovery rate; ② CO₂ in production wells has a lower density than water. The above two characteristics cause a greater pressure to drop

in the production wells in CO₂-EGS. Under the influence of Joule-Thompson expansion, the temperature of the CO₂ fluid is lowered, thereby reducing the potential power generation capacity of the system. Their sensitivity to different processes and reservoir parameters showed that in high-impedance and shallow reservoirs, CO₂-EGS produces similar instincts as water-EGS. In addition, as the diameter of the wellbore increases, the potential power generation capacity of CO₂-EGS increases, but their effect on water-EGS is not obvious. The above evaluation work provides a theoretical basis for the future site selection and design of geothermal power plants related to CO₂-EGS.

It should be noted that Pruess pointed out that the traditional enhanced geothermal system will cause the presence of an aqueous phase in the geothermal reservoir, and the use of CO₂ as a heat transfer medium to continue mining the geothermal resources in the reservoir is a potential geothermal energy. Increasing production measures, and the hydraulic fracturing method used to increase cracks in dry and hot rocks will also cause a certain amount of water in the cracks. The above situation will further increase the complexity of CO₂-EGS, so a more accurate and clear understanding of the following process is required: ① The multiphase flow process between supercritical CO₂ and the aqueous phase involves the immiscible phase of CO₂ to water Displacement, the dissolution of CO₂ in the water phase, and the dissolution of the water phase in supercritical CO₂, etc., which requires obtaining the thermophysical characteristics of the mixed state of aqueous solution and CO₂ under typical pressure and temperature conditions; ② Supercritical CO₂-water- The geochemical process of rock and supercritical CO₂-rock involves the dissolution and precipitation of minerals, changes in physical characteristics of the reservoir, etc.

Spycher et al. pointed out that under the typical temperature and pressure conditions of CO₂-EGS, the phase partition behavior between the water phase and the supercritical CO₂ phase will have significant changes, so the establishment of a wide range of temperature and pressure conditions of CO₂ and The phase distribution model of the mixed state of the aqueous solution is of great significance to accurately simulate the multiphase flow and the reaction solute transport process in CO₂-EGS. They improved the phase allocation model to increase the effective temperature range of the current model from the original 100 °C to 300 °C, which can basically meet the needs of simulating high-temperature geological conditions for CO₂ mining geothermal resources, and they used modified and The improved phase distribution model is the first to simulate the geothermal

exploitation of CO₂ in the aquifer geothermal reservoir. The simulation results show that, in the initial stage of CO₂ injection, the fluid produced by the production well is a single-phase aqueous solution. With the continuous injection of CO₂, the production rate of CO₂ in the production wells began to increase, while the production rate of the aqueous solution decreased. This shows that with the continuous injection of CO₂, the relative permeability of supercritical CO₂ increases. Finally, when no aqueous solution is produced in the production well, the fluid produced is only supercritical CO₂. It should be noted that the CO₂ production rate will increase significantly at this time, because the CO₂ under single-phase conditions is absolutely higher than the relative permeability of CO₂ under two-phase conditions; in addition, a certain amount of water will be dissolved in the supercritical CO₂ produced, and as the water in the reservoir gradually decreases, the water content in CO₂ will also gradually reduce. They also pointed out that the industrial design of CO₂-EGS previously envisaged for power generation is to directly add the generated CO₂ fluid to the turbine, so it can reduce operating costs and heat losses in heat exchangers. However, the above simulation results show that the produced CO₂ has a high content of water dissolved in it. Therefore, before adding CO₂ to the turbine, the produced fluid needs to be dried to avoid the formation of water condensation and low temperature and low-pressure conditions.

Based on the principle, feasibility and economy of CO₂-EGS, the research progress of CO₂-EGS is discussed, and the following conclusions are obtained. (1) For enhanced geothermal systems, as a potential heat transfer medium, supercritical CO₂ has greater advantages than water, such as CO₂ is a weak solvent for rocks, has greater compressibility and expansion, and lower viscosity, etc. However, in practical applications, it is also necessary to pay attention to the shortcomings of CO₂, such as lower density and specific heat, which are not conducive to the effective exploitation of geothermal resources. (2) The use of supercritical CO₂-EGS, while mining geothermal resources, also helps to reduce greenhouse gas emissions. (3) For geothermal reservoirs that are potentially used for geothermal development, at lower initial reservoir temperature conditions, the increase in thermal recovery rate is more pronounced, and under different initial reservoir pressure conditions, supercritical CO₂ geothermal exploitation of CO₂ reservoirs may show some unique characteristics, depending on the temperature and pressure conditions that affect the mobility of CO₂. (4) For the engineering design of CO₂-EGS, the increase of the injected CO₂ temperature and

the decrease of the borehole diameter are not conducive to the effective exploitation of geothermal resources.

6. Additional Support for EGS Plant

6.1 Communication

The construction of the communication system of this project is to provide a bearing network for the SCADA data, voice and video transmission of the process stations related to crude oil long-distance transportation, and at the same time set up video surveillance camera front ends and amplified broadcast telephone terminals for each process station.

At present, there are three commonly used transmission methods at home and abroad: optical fiber communication, wireless broadband communication and satellite communication.

The selection of the technical solution of the engineering system should save investment as much as possible on the premise of meeting the technical requirements, and the satellite communication method has a large investment, the capacity is relatively small compared to the optical fiber communication, and the performance-price ratio is at a disadvantage. Therefore, the satellite communication method is not suitable for this project. No further discussion will be made in this design. The optical fiber communication mode has large transmission capacity, long relay distance, stable transmission quality, and is not disturbed by external factors. The wireless broadband communication method has flexible networking, high transmission rate, and easy expansion.

According to the actual needs of this project, the communication system must not only be safe and reliable, but also save investment as much as possible. Therefore, comprehensive analysis is considering the actual situation of the project, but higher requirements for transmission quality, optical cable communications in the formal development stage can be easily incorporated directly into the new optical fiber communication transmission network. Based on the comprehensive situation, the design recommends the use of optical fiber transmission communication as the communication transmission scheme of this project.

Considering the actual situation of this project, the optical fiber transmission system considers the use of multi-service uncompressed video optical transmission equipment networking. Install light receiving equipment at the loading station and light emitting equipment at the remaining stations. The system carries SCS data, video and control signals and voice transmission services from the joint station to the loading station.

6.2 Power Supply and Distribution

6.2.1 Power Supply System

This design builds a 110kV substation near the first station of the overseas transmission to provide power for the entire project area.

6.2.2 Lightning Protection and Static Grounding

According to the requirements of “Code for Design of Lightning Protection of Buildings” (GB50057) and “Code for Design of Grounding of Industrial and Civil Power Installations” (GBJ65), all structures, stations and process pipelines shall be provided with necessary lightning protection and anti-static grounding according to the specifications, Working ground and protective ground.

Each station’s transformation and distribution room is provided with a ring-shaped closed common grounding grid, the grounding resistance is less than 1Ω , and the metal shell and process equipment of all live equipment are grounded for protection.

For buildings that need protection against direct lightning strikes, $\Phi 10$ galvanized round steel is used as the lightning protection belt, and $\Phi 10$ galvanized round steel is used as the downline. The metal pipes and devices protruding from the roof are reliably connected to the roof lightning protection device.

There shall be no less than 2 connection points between grounding trunks and grounding devices for lightning protection in all buildings. The metal pipes introduced into and out of the building should be connected to the lightning protection grounding device at the entrance and exit, and the overhead metal pipes should be grounded once at a distance of about 25m from the building. The impact ground resistance is not greater than 100Ω .

The main metal objects such as equipment, framework, pipelines in the house should be connected to the lightning protection grounding device or the protective grounding device of the electrical equipment. All pipes and equipment that may be exposed to static electricity in the outdoor are connected into a continuous electrical path and grounded. The grounding resistance is not greater than 30Ω .

Bare metal brackets are placed outside the entrance of the explosion hazardous environment as anti-static facilities and there should be obvious signs, and the metal brackets should be grounded. In the production process, anti-static shoes, anti-static work clothes, anti-static gloves and other personal static protection facilities should be used; static test equipment should be provided to grasp the amount of static electricity carried by yourself before

entering an explosion-proof place to take measures. The antistatic grounding resistance is not greater than 100Ω .

6.2.3 Laying Method of Distribution Lines

The power distribution adopts copper core insulated cable, the indoor part is laid underground through steel pipes, and the outdoor part is laid directly buried with armored cables. The lighting circuit adopts copper-core insulated wires through steel pipes and is dark-matched along the wall and the roof insulation layer. The lighting circuits in explosion and fire hazard locations are equipped with steel pipes. The selection of the cross-section of insulated wires and cables shall comply with the relevant regulations and be determined through calculation.

6.2.4 Electric Lighting Distribution Design

Install emergency emergency lighting in substations and power distribution rooms. Electrical lighting in explosion and fire hazard locations should meet explosion-proof requirements. The illuminance standard implements “Building Lighting Design Code” GB50034 2004. According to different lighting requirements, the light source of the lighting fixture is selected to comply with the relevant national standards and standard equipment products. Among them, the road lighting in the station is planned to use a mixed sodium and mercury light source, the light pole uses a steel column, and PVC power. Buried cable laying, photoelectric automatic control and manual control.

6.2.5 Communication

Power distribution of instrument automation system and instrument automation do not allow uninterrupted power supply. Therefore, non-interruptible power supply (UPS) is used. For UPS power supply, see the communication and automatic control section.

6.3 Building Structure

In order to improve the level of earthquake resistance, the seismic intensity of this design is 7 degrees, and the basic earthquake acceleration value is 0.1g. In general, buildings take earthquake-resistant fortification measures according to the corresponding fortification intensity. First, select a structural system that meets the requirements of seismic fortification intensity. The plane and floor layout and shape treatment of buildings should avoid and reduce the seismic weak links as much as possible. Energy absorption and dissipation structure. For class B buildings, the “Classification Standards for Seismic Fortification of Construction Projects” (GB50223-2008), and according to the “Code for Seismic Design of Buildings” (GB50011-

2010), take seismic measures in accordance with the requirements to increase the seismic fortification intensity of the region by one degree. Except for the control center building, compressor room, and empty torch tower, the seismic fortification category is Category B, and the other buildings and structures are considered as Category C.

Because the project area belongs to the mid-temperate semi-humid and semi-arid continental monsoon climate. How much wind and little rain in spring, large evaporation; cool and short in summer, concentrated precipitation; rapid fall in autumn, early frost; long cold in winter, long snow area. The monthly minimum temperature is $-37.8\text{ }^{\circ}\text{C}$, and the monthly maximum temperature is $32.9\text{ }^{\circ}\text{C}$. The annual sunshine hours are 2049.5 trivial, and the frost-free days are 126 days. The architectural design focuses on thermal insulation in summer and thermal insulation in winter. According to the "Code for Thermal Design of Civil Buildings" (GB50176-93), the building should not be too large from the direction, shape factor, unevenness of the flat facade, the area of the external window of the building should not be too large, double-layer windows, stucco insulation coating Consider thermal insulation of buildings.

6.4 Heating and HVAC

6.4.1 Design Principles

Strictly follow the current national standards of thermal engineering and HVAC, and the compromise documents formed by the current national standards, and design in accordance with the principles of practicality, advancedness and economy. Adopt high-efficiency, low-consumption, low-pollution equipment, implement the "safe and reliable" guiding ideology, simplify the technological process, achieve the purpose of saving investment and reducing operating costs. Fully consider environmental protection, soil and water conservation and energy conservation.

6.4.2 Heating

According to the heat load requirements for the production of process devices in each station of the block, the heating load of individual building heating in winter in the plant area, and the heat load for process heat tracing, etc., the automatic heat conduction oil furnace heating system is used for the whole plant. Heating. The scale of the heating station is 2 automatic heat conduction oil furnaces, with a single heat load of 8000kW, and the operation mode is 1 for 1 standby; according to the requirements of the heating parameters for the domestic base hot water for the operation base and the winter heating load of the building

unit, etc. , It is planned to use a hot water boiler to heat the operation base. The design scale of the boiler room is 2 hot water boilers, with a single heat load of 1.4MW, and the operation mode is 1 set for 1 use.

6.4.3 Keep the Room Warm

The control room uses a heat pump type cabinet air conditioner with auxiliary electric heating to meet the requirements of cooling in summer and heating in winter. In order to meet the environmental temperature and humidity requirements of process equipment and instruments in the duty room, air conditioners and electric heating devices are installed.

6.4.4 Ventilation

The ventilation of the plant is a combination of mechanical ventilation and natural ventilation. Some production plants will emit toxic gases during production operation. In order to reduce the concentration of toxic gases to the allowable range of hygienic requirements or to eliminate indoor residual heat, forced ventilation with natural air intake and mechanical exhaust may be adopted. Axial fans or the roof fan is fully ventilated to remove harmful gases and indoor residual heat.

6.5 Automation Control

The SCADA system should be used for production and operation management in this project area. In order to ensure safe production and improve management level, this project sets up a production monitoring system (e.g. SCADA system) for the entire block. The production monitoring system (SCADA system) is divided into three layers from the logical structure:

The first layer is the production management, decision-making, dispatch and command system, which is the production monitoring system with the SCADA central control system as the core; the second layer is the monitoring system located in each station, which is the control and management of each production operation area; The third floor is a small station control system located in each intermediate station and valve room.

The central control system of SCADA system (that is, the management, scheduling, and decision-making system of the central processing plant) is located in the production dispatching command center of the loading station, with a complete and unified production database and application database, and centralized production monitoring of each station under its jurisdiction , Scheduling and management. The station control system of the SCADA system is a monitoring system set up in the station yards along the

line. Responsible for the data collection and processing of the production process and the automatic control and process management of the production process; and collect and monitor the production operation to realize the centralized scheduling and management of the production operation area. At the same time, upload the production data and production information to the central control system, accept the production command and scheduling instructions of the control center, and complete the specific realization of the production plan.

6.6 Fire and Explosion Protection

6.6.1 Causes of Fire and Explosion

The subjective cause of the fire in the oil tank area is often due to the lack of attention of the personnel concerned, paralysis, inadequate system, poor management, and violation of operating rules. The objective reasons are:

(1) When the electrical equipment is short-circuited, the contacts are separated, the shell is poorly grounded, etc., the arc and spark are caused, or the heating part of the electrical equipment exceeds the maximum allowable temperature;

(2) Sparks caused by metal impact;

(3) Static electricity and lightning;

(4) Spontaneous combustion of combustibles, such as sulfur-containing oil deposits in oil tanks spontaneously ignited during removal, and accumulated oily garbage spontaneously ignited;

(5) Fire spread around the oil depot, etc.

6.6.2 Fire and Explosion Prevention Measures

The oil tank in the ground oil tank area is exposed above the ground, the target is obvious, and it is greatly affected by external factors, especially the risk of fire is large. After the accident, the oil products are easy to flow, causing damage and involving a large area. Therefore, it is necessary to enclose the fire dike around the oil tank or oil tank group. According to the requirements of GB50074-2002 "Code for Design of Petroleum Depots", the fire separation distance between oil tanks should meet the requirements of Table 8.1, the oil tanks in the group should be arranged in a row or two lines, and the distance between the slopes of the two oil tank firewalls should be greater than 9.5m.

In addition to setting up fire dikes, it is also necessary to avoid fire and explosion by establishing a sound management system:

(1) Formulate Relevant Rules and Regulations

Establish a mass fire-fighting organization, formulate fire-fighting regulations and fire-fighting plans, divide

fire-fighting areas, specify fire alarm signals, regularly organize fire-fighting education and fire-fighting exercises, and be skilled in using fire-fighting equipment.

(2) Cut off the Fire Source

① It must be strictly managed in the fire restricted area (oil storage area, receiving and sending operation area), and strictly abide by the relevant rules and regulations. No fires, such as matches and lighters, are allowed in the fire restricted area; smoking is not allowed; steam locomotives are not allowed to enter the warehouse. The front chimney should be covered with a fire hood, fly out with a fire star, and close the gray door; it is forbidden to open the blower and put down the gray box baffle in the warehouse, and do not open the steam door and remove the water from the furnace; when the locomotive enters the warehouse, there must be several isolation vehicles between the tank truck and the locomotive; the locomotive should be reversed into the warehouse; the locomotive should leave the tank truck as soon as possible after entering the tank area; the vehicle is not allowed to drive in the restricted area;

② Prevent sparks caused by metal impact, and do not wear iron spiked shoes for storage; mules and iron wheels are forbidden to enter the storehouse. Because the horse-shoes and iron wheels of the horses collide with gravel or cement roads on the road, sparks are prone to occur; use metal tools and When handling oil drums, avoid collisions to avoid sparks;

③ No open flames (such as oil lamps, candles, etc.) should be used for lighting, nor should ordinary electrical equipment be used for lighting. In order to prevent electrical equipment from causing sparks due to short circuits, contact separation, etc., explosion-proof electrical equipment must be used in the restricted area;

④ In the event of thunderstorms, do not load, unload, measure and sample gasoline, kerosene and diesel fuel.

(3) Do a good job in fire prevention of dangerous operations

Open flame operations such as electric welding, gas welding, and forging in the oil depot area are the most stringent safety requirements and relatively dangerous operations. Therefore, they must be carried out in strict accordance with regulations. Before conducting an open flame operation, a fire application must be submitted. After approval, effective fire safety measures should be taken before the fire can be used. When working with fire, firefighters who are able to cope with any situation should be assigned to be on duty, and be prepared for first aid in the event of an accident.

(4) Handle combustible materials

The treatment of combustibles in the oil depot includes

the treatment of the oil itself and other combustibles that cause the oil to catch fire.

① Prevent oil vapor accumulation and oil leakage and splashing. When the oil vapor concentration exceeds the safety regulations, mechanical ventilation or natural ventilation should be used to remove the oil vapor, or measures should be taken to collect oil and gas so that it will not escape into the air as much as possible. When oil is spilled, cover with sand or shovel clean;

② Fire dike or firewall should be built on the ground oil tank;

③ In order to prevent the spontaneous combustion of sulfur-containing materials, when removing the sediments of sulfur-containing crude oil tanks, the sulfur-containing sediments should be continuously wetted with water. After the sulfur-containing sediments are taken out, they must be transported away and buried in the soil while wet. Oily gauze and rubbish should be placed in covered iron drums and removed in time. Do not stack them in a place where there is no wind to prevent spontaneous combustion;

④ Dispose of other combustibles in time. It is forbidden to store and remove combustible materials, such as wood shavings, cotton yarn, hay, garbage, etc. around oil tanks, warehouses, pump rooms, etc.

(5) Ensure that firefighting equipment is in good condition and reliable

① The oil depot should have sufficient fire extinguishing equipment. In the warehouse, pump room, barrel room, laboratory, loading and unloading station, cavern and other places, sufficient fire extinguishing equipment and firefighting pool or fire hydrant shall be arranged. And set up fire-fighting points in appropriate places, equipped with all rescue equipment, such as buckets, fire hooks, shovel, axe, etc.;

② Fire equipment should be intact and reliable. It is necessary to check and maintain at ordinary times, and it is forbidden to use it for other purposes. Fire trucks and fixed firefighting equipment should be launched regularly. Always maintain good technical status.

6.7 Fire Protection at Station

6.7.1 Fire Extinguishing Principles and Methods

The principle of fire suppression is to destroy the combustion conditions. According to the three conditions of combustion and the chain reaction that constitutes flame combustion, three basic physical methods of cooling, suffocation and isolation are often used in firefighting technology to extinguish fire and chemical interruption.

(1) Cooling method

The purpose of the cooling method is to absorb the heat

released during the oxidation of combustibles. For burned substances, the temperature can be lowered to below the ignition point, while the decomposition process of combustibles is suppressed, and the speed of combustible gas generation is slowed down, causing the fire to be extinguished due to the "supply shortage" of combustible gases. For other combustibles in the vicinity of the combustibles, they can be protected from the threat of flame radiant heat and destroy the combustion temperature conditions.

(2) Asphyxiation

The suffocation method is to eliminate the combustion aid oxygen O₂, so that the combustion extinguishes itself when it is isolated from fresh air. The methods of using this method to extinguish fires are:

1) Use non-combustible or incombustible materials to directly cover the surface of the combustible materials to isolate fresh air;

2) Use water vapor or refractory gas to spray on the combustion products to dilute the oxygen in the air and reduce the oxygen content in the air to less than 9%. For example, the steam in the pump room extinguishes the fire;

3) Try to seal the holes and gaps of the burning container, so that the flame will extinguish after the air in the container is exhausted. For example, after a fire in a cavern, closing a closed door is one of suffocation.

(3) Quarantine

The isolation method is to isolate the fire source from combustible materials to prevent the spread of combustion. The specific methods are:

1) Quickly remove combustibles, combustibles, and explosives near the fire;

2) Demolition of combustible buildings and fire debris adjacent to the fire site in time;

3) Cut off combustible and flammable substances into the burning zone;

4) Limit the flow and splash of burning materials;

5) Move the movable combustibles to an open place, so that the combustibles burn under human control. For example, the tank truck caught fire and quickly dragged out of the warehouse.

(4) Chemical interruption method

Chemical interruption method is also called chemical suppression method to extinguish fire. It is a new fire-extinguishing technology developed rapidly in modern times. The new combustion theory believes that combustion is a chain reaction maintained by certain active groups. Chemical fire extinguishing means spraying a chemical fire extinguishing agent into the flame. With the help of chemical fire extinguishing agents, the generation and existence of these active groups are inhibited, and

the chain reaction of combustion is prevented to stop the combustion, thereby achieving the purpose of extinguishing the fire. Commonly used chemical fire extinguishing agents include dry powder fire extinguishing agent and high-efficiency halogenated fire extinguishing agent.

6.7.2 Fire Extinguishing Methods and Equipment

Foam fire extinguishing facilities and fire cooling water system should be installed in the oil tank area in the station.

(1) Fire extinguishing with foam

According to the design of fire extinguishing equipment, it is divided into fixed, semi-fixed and mobile fire extinguishing systems.

1) Fixed air foam fire extinguishing system It is a semi-automatic foam fire extinguishing device. This system means that all equipment is fixed. There is no need to connect other equipment when extinguishing the fire. When the oil tank fires, just start the water pump (prior to prime the pump before starting), open the pump outlet valve, rotate the foam proportion mixer pointer to the required foam liquid volume index, and mix. The device mixes the foam liquid automatically with water in proportion and transfers it to the foam generator through pumps and pipelines. After inhaling the air, the foam is formed and sprayed into the oil tank to cover the oil surface and extinguish the fire.

The fixed air foam fire extinguishing system has the advantages of no need to lay pipelines and installation equipment during fire extinguishing; rapid start-up, fast foam output; simple operation, saving manpower; low labor intensity and so on. The basic disadvantage is that the equipment has a large investment at one time, such as the collapse or explosion of the oil tank, and when the fire fighting equipment installed on the oil tank is damaged, the entire system loses the ability to extinguish the fire. Therefore, when the fixed air foam fire extinguishing system is used, a head is often left on the foam pipe network close to the oil tank area, so that when the fire fighting equipment on the oil tank fails, the mobile fire extinguishing equipment is replaced.

The fixed air foam fire extinguishing system is mainly suitable for oil tanks where the oil tanks are relatively concentrated, the number of independent oil depots and the oil tanks with few fire fighting lines required is relatively small, and the oil depots with complex terrain.

2) Semi-fixed foam fire extinguishing system

This system is equipped with a fixed foam generator on the oil tank and some auxiliary pipelines underneath (it should be connected to the fire dike of the oil tank, about 1 m above the ground, and the end should also be installed

with an interface, usually equipped with a boring cover) Outside, cover), other equipment is removable. In case of fire, drive the fire truck with foam liquid to the scene, take water from the reservoir or fire hydrant, and supply the foam mixture to the foam generator fixed on the oil tank with a temporarily installed hose.

Since the water for preparing the foam mixture comes from the cooling water pipe network, there is no need to set up a special foam pipe network, so the construction investment and maintenance cost of this system are lower than the former, but it requires a motorized fire truck and a water pump, and a certain amount Operator. It is suitable for oil depots with relatively flat terrain.

3) Mobile foam fire extinguishing system

The mobile foam fire extinguishing system is to replace the foam generator on the fixed oil tank by foam guns, foam guns or foam hook pipes, foam pipe racks and other equipment. The equipment and equipment are movable, so it is called the mobile foam fire extinguishing system. It has the advantages of good safety, flexible use, low investment, etc., but the operation is complicated and the preparation time for fire extinguishing is long. It is suitable for oil depots with many oil tanks, scattered layout and relatively flat terrain.

According to the requirements of GB50074-2000 "Code for Design of Petroleum Depots", since the loading station uses three 3000m³ floating roof tanks, the foam fire extinguishing facility uses a fixed foam fire extinguishing system.

(2) Fire cooling system

For firefighting of oil tanks, two systems should be considered, namely fire extinguishing system and cooling system. The cooling system is set to prevent the fire tank steel plate from softening and to protect the adjacent tank; on the other hand, it is also necessary for the fire extinguishing with foam. Because of the fire in the oil tank, the flame temperature is generally 1050-1400°C, and the temperature of the oil tank wall reaches above 1000°C. When the temperature of the tank wall exceeds 600°C, the foam cannot extinguish the tank fire. After the oil tank catches fire, the tank wall should first be cooled with water. When the temperature of the oil surface drops below 147 °C, it is possible to cover the fire with foam. Under normal circumstances, when the foam enters the combustion liquid surface, the foam evaporates and bursts very quickly. Because the foam evaporates, the oil is cooled. When the oil surface temperature drops below 147 °C, the foam layer can advance on the combustion liquid surface to burn. The surface continues to decrease, and finally covers the entire combustion liquid surface to extinguish the fire. At this time, the foam continues to burst (evaporate) until the

oil temperature drops below 98 °C, the foam evaporation is gradually reduced, and then, the oil surface temperature continues to drop until it reaches the liquid surface temperature before combustion.

According to the requirements of GB50074-2000 "Design Specification for Petroleum Depot", since the loading station uses three 3000m³ floating roof tanks, the fire-fighting cooling water system adopts a mobile cooling water system or a combined fire-fighting cooling water system with a fixed water gun and a mobile water gun.

6.8 Lightning Protection

A large number of flammable and combustible fuels are stored in the oil tank. Once a lightning strike occurs, serious fire and explosion accidents may occur. Therefore, the problem of oil tank lightning protection has attracted people's attention.

The current commonly used lightning protection devices to prevent oil tanks from direct lightning strikes include lightning rods, lightning protection lines, lightning protection nets, lightning protection belts, and lightning arresters. A complete set of lightning protection devices includes air-termination devices, down conductors and grounding devices. The above needles, wires, nets, and belts are actually just lightning receptors, and the lightning arrester is a special lightning protection device. The lightning rod is mainly used to protect open-air substation equipment and protect buildings (structures). Lightning conductors are mainly used to protect power lines. Lightning protection network and lightning protection belt are mainly used to protect buildings. Lightning arresters are mainly used to protect electrical equipment. In short, the lightning protection device can prevent direct lightning strikes or the introduction of lightning currents to the ground to ensure the safety of people and buildings (structures). There are generally two types of floating roof oil tanks: an outer floating roof oil tank and an inner floating roof oil tank. Three 3000m³ outer floating roof tanks are installed in this loading station. The outer floating roof oil tank is tightly sealed, and the oil product has a small area of contact with the atmosphere and direct contact with the atmosphere. The mixed gas of oil vapor and air on the floating roof is not easy to reach the explosion limit, even if a lightning strike catches fire. It also happens only when the sealing ring is not strict, and it is easy to extinguish. Lightning rods are not required. In order to prevent the induction of lightning and the static charge from the oil away to the metal floating roof, two soft copper strands with a cross-sectional area of not less than 25mm² should be used to make a good electrical connection between the metal floating roof and the tank, and ground.

6.9 Anti-static

The friction between two different substances is a special form of static electricity, but it is not the only way. In addition to friction, the separation of two different substances in close contact, the pressure or heat of the substance, the electrolysis of the substance, and the induction of the substance by other charged objects may generate static electricity. When the liquid phase and the solid phase, between the liquid phase and the gas phase, between the liquid phase and another incompatible liquid phase, and between the solid phase and the gas phase, due to flow, stirring, sedimentation, filtration, scouring, spraying, The relative motion of contact and separation such as perfusion, splash, violent shaking and foaming will generate static electricity in the medium. Many petrochemical products are highly insulating substances. During the production, storage and transportation of this type of non-conductive liquid, a large amount of static charge is generated and accumulated, and spark discharge can occur when the static electricity accumulates to a certain extent. If there is also explosive gas in the discharge space, it may cause fire and explosion. Therefore, it has very important significance for the anti-static hazard in the oil depot.

The generation of static electricity control is mainly to control the process and the selection of all materials in the process; the accumulation of static electricity is mainly to try to accelerate the leakage and neutralization of static electricity so that the static electricity does not exceed the safety limit. Grounding and the addition of antistatic additives are all methods of accelerating electrostatic leakage; methods of using static elimination devices to eliminate electrostatic hazards are methods of accelerating electrostatic neutralization.

(1) Reduce the generation of static electricity

Impurities in oil products are important factors for electrostatic charging, however, it is difficult and uneconomical to achieve high precision in oil products. From the current state of technology, there are no measures that can completely prevent the generation of static electricity. Therefore, in order to prevent the damage of petroleum static electricity, the generation of electrostatic charge cannot be eliminated, and only the technical measures to reduce the generation of static electricity are available.

1) Control flow rate

It is known that the saturation value of the flowing current and charge density generated by the oil flowing in the pipeline is proportional to the square of the oil flow rate. Controlling the flow rate is an effective way to reduce the

generation of static electricity. When the oil is in laminar flow, the amount of static electricity generated is only proportional to the flow rate and has nothing to do with the inner diameter of the pipeline; when the oil product is turbulent, the amount of static electricity generated is proportional to the 1.75th power of the flow rate.

The flammable and combustible liquid flowing in the pipeline, even with a higher average charge density, often does not show a higher electrostatic voltage due to the larger capacitance in the pipeline, and because there is no air in the pipeline, So it will not cause burning and explosion. In this case, although static electricity does not constitute a danger inside the pipeline, its serious harm is mainly at the outlet of the pipeline, which must be paid attention to. For example, China's oil tanker loading test shows that when the average flow rate is 2.6m/s, the measured oil surface potential is 2300V; when the average flow rate is 1.7m/s, the oil surface potential is 580V (because the tanker is on the ground) The capacitance is constant, the greater the charge, the higher the potential). Therefore, controlling the flow rate becomes an effective measure to reduce the generation of static electricity in oil products.

According to GB50074-2002 "Code for Design of Petroleum Depot", the filling flow rate of gasoline, kerosene and light diesel oil is not more than 4.5m/s. Some national regulations. When oil is injected from the top, before the oil injection pipe mouth is submerged, before the oil inlet pipe inlet at the top of the oil tank is not submerged, before the floating roof oil tank is not floated, when water or air is trapped in the product oil or flammable liquid, install The oil speed is limited to less than 1m/s.

2) Control the fueling method

This loading station adopts the method of upper oil loading, in order to reduce the impact of oil loading on the tank wall, reduce the agitation of crude oil in the tank, and reduce the accumulation of static electricity. When loading oil, the crane pipe should be extended close to the bottom of the tank truck. this is okay:

- ① Reduce oil splashing and foaming to avoid the generation of new charges;
- ② Reduce the atomization and evaporation of oil, and avoid the ignition of oil when it reaches the flash point temperature;
- ③ Avoid oil flow through the middle of the oil tank with the smallest capacitance, so as not to generate a large oil surface potential;
- ④ It can avoid the formation of high oil surface charge density due to the concentrated drop of oil column in a local range;
- ⑤ In the later stage of oil filling, when the oil surface

potential reaches the maximum value, there is no protruding metal grounded on the upper part of the oil surface, which can avoid the increase of local electric field and prevent spark discharge.

3) There is enough leakage time when passing through the filter

The filter is a source of static electricity. The oil passing through the filter, due to the dramatic friction with the filter, greatly increases the strength of contact and separation, which may increase the voltage of the oil by 10-100 times.

In order to avoid injecting large amounts of charge into the container. In the oil pipeline connected with the filter, a certain length should be left at the outlet or flowed for a certain time, the ground charge will be leaked out, and then injected into the container. This length should be $L \geq 3L_b$ is called the relaxation length, if it is calculated as time, it is $t \geq 3\tau$, which is called the relaxation time or residence time.

When the length of the pipeline is limited and cannot meet $L \geq 3L_b$, consider designing a container so that the oil has a temporary relative residence in the container, and its residence time $t \approx 3\tau$. This container is called a moderator. General engineering only requires that the amount of charge leak to a level that does not cause danger, so it can be considered that the residence time $t \approx 2\tau$ can meet the requirements. It is generally stipulated that the oil passing through the filter must have a relaxation time of more than 30s. Therefore, the oil passing through the filter must continue to flow through the pipe length of more than 30s in the grounding pipeline before it is allowed to enter the container.

In order to avoid static electricity accidents. The reasonable arrangement of equipment pipelines has a great relationship with the control of static electricity. For example, the filter should not be close to the oil tank or the oil loading platform, and a certain length of relaxation should be left; the pipeline should be free of bends and diameter changes. Where rubber hoses must be used, conductive rubber tubes or conductive plastic tubes are preferred.

(2) Accelerate static electricity leakage and reduce static electricity accumulation

The generation of static electricity itself is not dangerous. The actual danger is the accumulation of electric charge, because this can store enough energy to generate sparks to ignite the combustible gas mixture. It is generally believed that when the resistivity of the insulator is less than $10^8 \Omega \cdot m$, there will be no dangerous static electricity accumulation. However, the resistivity of oil products is almost greater than $10^8 \Omega \cdot m$, and the

charge in the oil products is not easy to leak, so the more static charges that are generated in the oil products are accumulated. In order to accelerate the leakage of oil charge, it can be grounded, bridged and increased the conductivity of the oil.

(3) Eliminate spark discharge

In order to eliminate spark discharge, the bottom of the tank must be cleared before filling the tank, and no floating conductors and other debris that fall into the tank, such as liquid level gauge floats, measuring cylinders, gaskets and other metal objects. Testing and sampling must be carried out in the oil measuring tube. If no special oil measuring tube is installed, such as conducting a simple sampling, dipstick, etc., these metals are also equivalent to spark initiators on the oil surface. According to relevant information, when oil tank cars are refueled, the discharge phenomenon will occur when the oil surface potential reaches about 28kV, but when there are free insulating metal objects on the oil surface, that is, there are quite a few charge collectors, as long as 1~2kV. There will be a discharge.

When the oil in the oil tank is finished, it must not be tested. This is because the maximum value of the oil surface potential sometimes occurs after the oil tank is stopped during the oil tank filling process. For safety, when it is necessary to directly measure the liquid level or oil temperature, the leakage time of the static charge in the tank should be avoided. Generally, it takes about 30 minutes to allow the settling charge in the oil to leak before it can be detected. The crane pipe of the tank truck is also a promoter of spark discharge. The crane pipe is well grounded to avoid the spark discharge of the crane pipe and the inner wall of the tank truck. However, the spark discharge of the crane pipe and the oil surface may still occur. Therefore, before changing to bottom filling, the crane pipe should be extended to the bottom of the tank truck to fill the oil; the oil injection pipe that extends into the oil tank should be as close as possible to the bottom to avoid the end of the oil filling (At this time, the oil potential is the highest) the oil surface and the protruding part of the crane pipe (oil injection pipe) are discharged. Therefore, when carrying out the oil filling operation, do not stand on the tank top, let alone do other operations.

7 HSE Risk Management for EGS

“HSE” is the abbreviation of Health, Safety and Environmental Management System. H is Health, S is Safety, E is Environment, and HSE management system is a common management method in the international petroleum industry.

7.1 HSE management of Injection and Production Pipeline

7.1.1 Analysis of Hazardous Factors for Pipelines

(1) pipelines are transported by surface, buried, etc. In the season of heavy precipitation, natural geological disasters such as mudslides, landslides, landslides caused by flash floods and floods caused by river floods often occur in the region. These disasters may cause damage to the pipeline.

(2) Factors such as poor pipeline anti-corrosion quality, mechanical damage to the anti-corrosion layer caused by pipeline construction, soil moisture, salt, alkali, and underground stray current will cause pipeline corrosion, and in serious cases, cause pipe perforation and cause accidents.

(3) When the pipeline is cleared during the operation period of the external pipeline, there may be too many corrosion products in the pipeline, which will cause the pig to be stuck, thereby forming an overpressure pig, which will cause the risk of pipeline and equipment holding back and rupture.

(4) Due to the incomplete purge and replacement of the device before it is shut down for maintenance, or the maintenance site is not well separated from the toxic medium, the maintenance personnel may be in a limited space during the process of disassembly, knocking, hot work, dynamic welding, etc. Poisoning or suffocation.

7.1.2 Safety protection measures of pipeline system

The safety of pipeline system engineering generally includes the safety of design, construction, operation management, external transportation, etc. There are many emergencies on pipelines and gathering and transportation facilities, such as pipeline leaks and fires. First of all, different measures should be taken according to different emergencies to ensure that the damage and impact of the emergencies on the public, environment, and property are minimized. Considering the safety during the design, construction and operation of the project, it should meet the relevant regulations in SY618-1996 “Safety Regulations for Oil and Gas Pipelines”.

(1) Security measures

Reasonable use of advanced and mature design technologies and products at home and abroad; follow national safety production regulations, design documents comply with standards; strictly divide the scope of hazardous areas, and propose corresponding technical requirements, measures, supporting settings and operating points during design, and implement hazardous Provisions for grade division; fully consider the integrity and reliability of the oil pipeline safety system. Carry out hierarchical manage-

ment on the safe operation of pipelines. Responsibility is assigned to people. Production management and operation personnel should have a strict job responsibility system; prepare safety management regulations and regular inspection plans; formulate and enforce safety training plans for all employees; establish engineering technology Files and records of accidents; establish a complete system of line inspection, maintenance, and transformation; formulate and strictly implement regulations on labor safety and health.

(2) Environmental protection measures

1) Influencing factors of engineering environment

The environmental impact of the project during the construction period mainly comes from the construction of station yards, construction access roads and pile yards, leveling construction belts, excavation of pipe trenches, construction machinery, vehicles, and trampling of soil, etc. Impact on land use types and agricultural production. In addition, the exhaust and noise emitted by various machinery and vehicles during construction, the amount of solid waste discarded during construction, and the wastewater generated by pipeline pressure testing will also have a certain impact on the environment. However, such impacts caused by the construction are temporary, and will disappear within a short period of time after the construction is completed (Table 3). The specific construction measures should be worked out according to the surrounding soil, vegetation, and environmental characteristics of the block, and a reasonable construction site and access road should be designed to isolate the agricultural block as much as possible, protect the vegetation, and control the waste and noise generated by the construction operation Within a reasonable range to minimize the impact on the environment.

Table 3. Environmental impact analysis of engineering construction team

Construction type	environmental impacts
Construction site and construction access road	Destruction of surface vegetation and soil structure
Pipe trench excavation	Change soil, affect vegetation growth and development
Construction transportation and photo album work	Produce multi-phase pollutants, exhaust gas, exhaust gas

2) Environmental impact during operation

The impact of various stations and pipelines on the environment during operation is relatively small, mainly air pollution and water pollution. The air pollution mainly comes from the discharge of pollutants from various stations. This kind of discharge is mainly the CO₂ produced by burning natural gas or crude oil during the operation

of the equipment into the atmosphere; in the event of an accident, the crude oil in the system must be emptied for inspection and repair work ; The period of pigging operations varies from 10d to 30d, each time the crude oil is discharged from several cubic meters to tens of cubic meters; the overpressure of the system in the first station and the loading station of the outbound transportation will empty the crude oil, and the probability of this situation is small. According to relevant information, compared with the analog survey, the frequency of occurrence is 1-2 times/year, and the duration of each time is 2-5min. The water pollutants discharged from the first station and the loading station are mainly domestic sewage. In addition, there is a small amount of wastewater discharged during the pigging operations at each station.

In addition to domestic garbage, solid waste discharged from the first station and the loading station of the outbound transportation will also generate a small amount of solid waste during dust removal and pigging operations. The main components are dust, welding slag and iron oxide powder. Through the above comprehensive analysis, the corresponding pollutant control system was worked out (Table 4).

Table 4. Pollutant control measures

Type of pollutant	Treatment measures
Water pollutant	The sewage discharged from the plant, the sewage from the pipe cleaning, and the clean water from the device maintenance are collected and collected into the sewage tank and then loaded and transported to the central treatment plant for treatment; the domestic sewage treatment is discharged after reaching the standard.
Waste residue	The waste generated during the short-term pigging operation enters the sewage tank, and a small amount of domestic garbage is regularly sent to the garbage treatment plant.
Noise control	Choose throttling, blowout prevention devices and metering equipment that meet noise standards.

(3) Energy-saving measures

Crude oil can not only transport large amounts of energy, but also consume energy. Therefore, conscientiously implementing the relevant energy-saving technology policies of the state and group companies, actively adopting energy-saving technologies and equipment, using energy reasonably, striving to reduce energy consumption, doing a good job in energy conservation, and economically and rationally delivering crude oil are important goals of the project design. According to the characteristics of well site and pipeline operation, the energy consumption of this project mainly includes the following aspects: fuel gas consumption of self-provided small generator set; fuel gas consumption of heating furnace; fuel consumption of external pumps and loading pumps; production water,

Electricity; Consumption in the event of an accident in the pipe network system or policy maintenance. From the perspective of energy saving, the following measures have been formulated:

- 1) Set up pipeline cut-off valves to divide the pipeline into several small sections to reduce the crude oil loss of the oil pipeline;
- 2) Imported products such as high-efficiency energy pumps and other energy-saving equipment and pipeline shut-off valves are used.

7.2 HSE Management of Station

7.2.1 Analysis of Hazardous Factors in Stations

(1) The main accident hidden points of the station are pressure vessels such as external pumps and oil storage tanks. The low-carbon steel inner tube with a certain corrosion resistance is selected for the heating furnace in this design station. From the perspective of its working environment, there is a large range of fluid disturbances, and the change of crude oil composition affects its working life under certain conditions. At present, there is no full-scale monitoring means, so it should pay special attention in the production operation. If periodic inspection or replacement measures are not adopted, it is easy to cause corrosion, hydrogen embrittlement, explosion, fire and other major accidents.

The working conditions of the oil storage tank are also more complicated. Although internal anti-corrosion measures are adopted, they may also cause leakage or burst due to factors such as blockage, local pitting corrosion and valve failure, and cause major fire accidents. In addition, arcs and electric sparks caused by short circuit, grounding of the shell, and separation of contacts of the electrical equipment in the station may cause fire and explosion.

(2) Hidden dangers in station yards are the most prone events, mainly the hazards of crude oil leakage. Often caused by corrosion of pipes and devices and seal failure, or incomplete cleaning before maintenance.

(3) Hidden danger of emergency overpressure system. Generally, emergency shut-off valves are used to limit crude oil emissions during system process design, but when a certain emergency situation occurs in the treatment plant, only full venting measures can be taken, resulting in short-term excessive leakage, which is easy to produce pollution and cause human and animal environments. influences.

7.2.2 Security Measures for Stations and Yards

(1) Safety precautions

Strict implementation of the “Design Standards for

Industrial Enterprises” (GBZ1-2002). Conscientiously implement the principle of “safety first, prevention first”, and implement the current standard specifications in the design, so that the joint station, the first station of overseas transmission, and the loading station can meet the safety and health requirements, and all devices achieve long-term and stable production. The safety and health of employees in the process are not compromised. Therefore, the following protection work should be done:

1) Explosion-proof

The focus of explosion protection is on piping systems, pressure vessels and electrical installations. For the former, inspection and regular maintenance should be strengthened, and for the latter, it should be carried out in strict accordance with the “Code for Design of Electrical Devices for Explosive and Fire Hazardous Environments” (GB50058-92).

① Safe and reliable process equipment that is not easy to leak and low noise is used in the station.

② Seriously check the quality of equipment, materials and construction and installation quality, and minimize the unsafe factors; all pipes are made of seamless steel tubes that meet the standards, have good processing performance and good weldability; the welders must be qualified Certified welder; construction personnel should operate in strict accordance with relevant specifications to ensure the quality of the project.

③ The overall layout of the station is in accordance with the design specifications to ensure the safe distance of each area.

④ Lightning and anti-static measures are taken at the station, lightning protection belts are installed, and the process equipment and pipelines are grounded to avoid possible natural gas leakage and fire or explosion due to lightning strikes or static sparks.

⑤ All pressure vessels in the station comply with the design, manufacture and safety management regulations of pressure vessels.

2) Fire protection

Strictly implement the “Code for Fire Protection of Petroleum and Natural Gas Engineering Design” (GB50183-2004) and set up a water fire protection system throughout the site; the safety emergency rescue station shall be on duty 24 hours to meet the fire protection requirements.

① Process fire protection. The process design adopts safe and reliable equipment materials, strict construction quality requirements to ensure the quality of the project; formulate strict and correct fire protection measures for repairs, be equipped with corresponding firefighting facilities, and have full-time and part-time firefighting supervisors on-site supervision.

② Prevention of fire and explosion. Provide employees with safety and fire prevention education and training so that employees can grasp the correct knowledge and skills of fire prevention and fire extinguishing, set up safety fire prevention supervision posts, and implement fire prevention policies that focus on prevention and combining prevention and control.

3) Anti-noise

① Select low-noise equipment, and pay attention to control the speed of fluid entering and exiting the separator in the design of the separator. The flow rate of fluid entering and leaving the separator can also be controlled by adjusting the opening of the valve during production.

② Reduce or limit the working and staying time of staff under high-decibel noise, and conduct regular medical examinations for staff who often work in noisy environments.

(2) Environmental protection and pollution prevention

This project fully considers the requirements of environmental protection in the design, strictly in accordance with environmental protection standards, and has adopted effective treatment measures for wastewater, waste gas, waste residue, noise and other pollution sources discharged during the production process.

① Sewage treatment

According to the requirements of the State Administration of Work Safety and the State Environmental Protection Administration, all water that may cause pollution to the environment will be monitored and discharged after passing and discharged into the sewage treatment plant if it fails. The volume of the accident pool takes into account the collection of fire water, rainwater and possible leaking liquids, which can ensure the pollution of the army's water environment in the event of an accident. The project wastewater mainly comes from the production wastewater discharged intermittently by the process equipment such as tail gas treatment, the initial rainwater in the plant area, the wastewater from the engineering shutdown and maintenance of the equipment, domestic sewage, etc. Sewage treatment and drainage shall implement the first-level discharge standard of the Comprehensive Wastewater Discharge Standard (GB8978-1996).

② Waste disposal

The wastes generated in this project mainly include waste residue and waste gas. Waste residues need to be transported to the garbage disposal station for treatment. The waste gas can be burned as fuel or directly emptied.

(3) Energy-saving measures

In order to reduce the energy consumption of the station, such as the combined station, the first station of overseas transmission, and the loading station, the following

energy-saving measures have been adopted:

① Select energy-efficient electrical equipment with advanced technology to increase the power factor of the power supply network and reduce the energy consumption of the power grid and electrical equipment itself.

② Adopt high-efficiency heat-insulating material, perfect heat preservation structure, reduce heat loss of equipment and pipeline.

③ Recover steam condensate as much as possible to improve the recovery rate.

7.3 Hse Management System Construction and Operation

7.3.1 HSE System Construction

Combined with the characteristics of the block, on the basis of extensive research on domestic and foreign safety management experience and lessons, combined with the understanding of previous field practice, a series of related systems have been formulated to form a complete HSE management system.

(1) Regulations on safety management of construction engineering

Strengthened the supervision and management of the safety production of the construction teams of construction projects. The safety and environmental protection department of the block construction project headquarters is fully responsible for the work safety supervision and assessment of each unit, and formulates corresponding safety and environmental protection measures for the construction unit, and strictly implements the pre-construction acceptance regulations according to the construction characteristics of the block.

(2) Work area safety and environmental protection training and education management system

Strengthen the safety and environmental protection training and education of the participants in the work area. All management and technical personnel in the work area should be considered: safety management, HSE and other qualification certificates.

(3) Notification of safety management of contractors in the work area

The project contractor is required to apply for safety construction qualification review to the safety and environmental protection department after obtaining the construction project contractor's construction qualification issued by the project management department. The project contractor must conduct HSE training and issue an HSE certificate after being evaluated by the safety and environmental protection department.

(4) Regulations on traffic safety management in con-

struction area

According to the climate and road conditions of the work area, please refer to the unit insisting on carrying out traffic safety education for all personnel and regularly carrying out team safety activities. The vehicle must strictly control the speed of the vehicle according to the road signs; it must master the changes in the rainy season and the river; check the braking system after the vehicle passes the water, drive at a low speed for a distance, and wait until the braking performance is restored before driving at normal speed.

7.3.2 HSE System Implementation

In order to ensure the effective implementation and operation of the above-mentioned HSE safety system, in line with the principle of “focusing on management outside and promoting learning internally”, the following work is carried out to connect and promote each other to ensure that the HSE system penetrates into all links.

(1) Implement graded safety supervision and management system

Established a unit supervision system and strengthened safety supervision and management responsibilities, and each grassroots unit of Party A and B is the grassroots execution unit of enterprise safety management as shown. The headquarters set up a safety and environmental protection department, and all participating units set up safety and environmental protection supervision agencies; each grassroots department is equipped with a full-time safety and environmental protection supervisor.

(2) Improve the grade requirements of engineering design and construction operations

The engineering design shall be carried out in strict accordance with the geological design, and the security measures for the inspection of engineering gathering and transportation shall be inspected. The Safety and Environmental Protection Department of the headquarters took the lead in organizing an expert group to carry out risk identification and risk assessment on key risk wells.

(3) Organize safety education and training for all employees

Pre-job training and education strictly follow the requirements. All staff who enter the area, no matter what position they have been engaged in or what professional training they have received, must strictly follow the principle of “training before going to work” and receive special training in safety and environmental protection projects to ensure that they have Improve the safety and environmental awareness and skills of the specific situation of the block.

7.4 Emergency Support System

In order to fully standardize emergency management work, establish and improve the emergency response mechanism of the region, quickly, orderly and efficiently organize various emergency response operations, rescue people in distress, and minimize the casualties and property caused by emergencies For loss and environmental damage, according to relevant national regulations, emergency plans for various accidents have been specially formulated.

7.4.1 Classification and Classification of Emergencies

(1) Classification of emergencies

According to the occurrence process, nature and mechanism of emergency events, through hazard identification and risk assessment, the block emergency events are divided into several aspects as shown in Table 9.3, so that different emergency treatments can be carried out for different emergency events. And the implementation of measures.

(2) Classification of emergencies

In order to effectively deal with all kinds of emergencies, according to the nature of the emergencies, the degree of harm, the scope of impact, the size of influence, casualties and property losses, it is divided into four levels from high to low: I (group company) level, II (headquarters) level, III (participation unit) level, IV (basic unit) level. The participating units shall classify the determined emergency events according to the nature, severity, controllability, impact range and other factors of the emergency event, and according to the setting of the organization.

7.4.2 Principles of Emergency Work

(1) Safety first, prevention first, all hands-on, comprehensive management, ecological protection, and pollution prevention

Emergency rescue work should follow the principle of prevention first and unremitting standing, strengthen the awareness of prevention, strive to reduce the occurrence of attempted incidents, make unremitting efforts to prevent accidents, and make all preparations for responding to emergencies to ensure the normal progress of all production.

(2) Putting people first, reducing harm, focusing on prevention, combining prevention with prevention

Effectively perform the management, supervision, coordination, and service functions of the functional departments of the headquarters and take the protection of employees' life and health as the primary task. The

headquarters and all participating units should make full use of the rescue forces of the enterprise, unit and nearby society, and establish an emergency rescue system with clear responsibilities, rapid response, powerful command and effective measures. Use the required resources and take necessary measures to minimize emergencies and the resulting casualties, hazards and environmental pollution.

(3) Integrate resources and coordinate responses

Integrate the existing emergency resources within the enterprise, make full use of social emergency resources, realize the organic integration of organization, resources, and information, and form an emergency management mechanism with unified command, responsiveness, complete functions, coordinated order, and efficient operation.

(4) Rely on technology to improve quality

Strengthen scientific research and the development of emergency technology, use advanced monitoring, monitoring, early warning, prevention and emergency response technologies and equipment to give full play to the role of experts, provide scientific and technological content and command level for handling emergencies, and avoid the occurrence of times Health, derivative incidents; strengthen publicity and education to improve the overall quality of employees' self-rescue, mutual rescue, and emergency response to various emergencies.

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