Energy Analysis of Geothermal Water in Medium and Low Permeability Reservoirs and the Design of Geothermal Water Replacing Surface Engineering Process Heat Suitable for Oilfields

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Abstract: With PetroChina promoting the integrated development of fossil energy and new energy, Daqing Oilfield has started the construction of a clean energy demonstration pilot. Technicians analyzed the distribution characteristics of geothermal water in Songliao Basin, and screened out the reservoir areas with large-scale hot water resources and good thermal reservoir properties. According to the energy demands of the oilfield, we carried out the plan and design of geothermal water replacing surface engineering process heat suitable for the oil area. The plan and design covered the design of heat exchange process, the selection of ground engineering metering, treatment equipment, and the control measures for pollutants. The plan not only made full use of geothermal water energy in medium and low permeability reservoirs, but also considered relying on existing stations and abandoned well pad equipment to reduce the cost of test and engineering construction. We hope that the plan and design would provide guidance for accelerating the construction of new energy pilot demonstration projects and exploring the road for the green transformation of oil fields.

Keywords: Geothermal water, Songliao Basin, Ground engineering, Exchange process

1 Introduction

In the context of concern about global climate change and carbon emissions, the 2020 Central Economic Conference pointed out that Chinese carbon dioxide emissions will strive to reach a peak by 2030, and strive to achieve carbon neutrality by 2060 .At present, the total installed capacity of direct geothermal utilization in Europe is estimated to be 4701.7 MW, accounting for about 43% of the global installed capacity[1]. The methods of geothermal direct utilization include: district heating, bathing and swimming heating, greenhouse heating, aquaculture pond heating, industrial heating, agricultural drying and snow melting, etc[2]. China will accelerate the adjustment and optimization of industrial structure and energy structure, furthermore vigorously develop new energy sources such as geothermal energy.

In July 2020, in accordance with the requirements of China National Petroleum Corporation's

"Notice on the Development of the Special Plan for the "14th Five-Year Plan" High-quality Development of Oilfield regions", Daqing Oilfield has launched the construction of pilot demonstration areas, carried out the preparation of demonstration area plans. Implementation measures are "actively promote the development and utilization of geothermal, industrial waste heat, wind energy and solar energy, accelerate the construction of green pilot demonstration projects". Main purposes of these work are to built clean energy alternative demonstration projects by block as a unit, to maximize the use of clean energy for oil and gas production, and to lay a solid foundation for creating a comprehensive and internationally competitive oilfield.

2 Energy analysis of geothermal water in northern Songliao Basin

Explorations show that the thermal storage system in the northern Songliao Basin is semi-deep-deep lacustrine sedimentary, which was formed when the basin was in the maximum subsidence period. There are multiple barrier layers and reservoirs distributed vertically. The sediment of this area is stable and the mudstone is pure. Moreover, the thickness is large, the distribution area is wide, and the sealing performance is good. It is a very good regional water barrier. The Qingshan I mudstone is the main water barrier layer, and the thermal storage system is formed vertically (Fig. 2-1). Above the Qingshan I barrier is the upper thermal storage system. The water heat resources are mainly composed of Qingshankou II III section and Yaojia section. Below the Qing I compartment and above the Quan II compartment, is the middle heat storage system, which is composed of the Quentou III IV section, and is dominated by hydrothermal resources[3]. Below the Quantou II mudstone is the lower heat storage system, composed of the strata below the Quantou section (Fuyang oil layer and natural gas layer), which is deeply buried and mainly consists of dry heat resources. Dry heat resources development requires the use of enhanced geothermal system technology, the use of artificial formation of geothermal reservoirs, low-permeability rock from the economic extraction of deep thermal energy of the artificial geothermal[4]. Enhanced geothermal system technology will be the next direction of the 15th five-year plan.

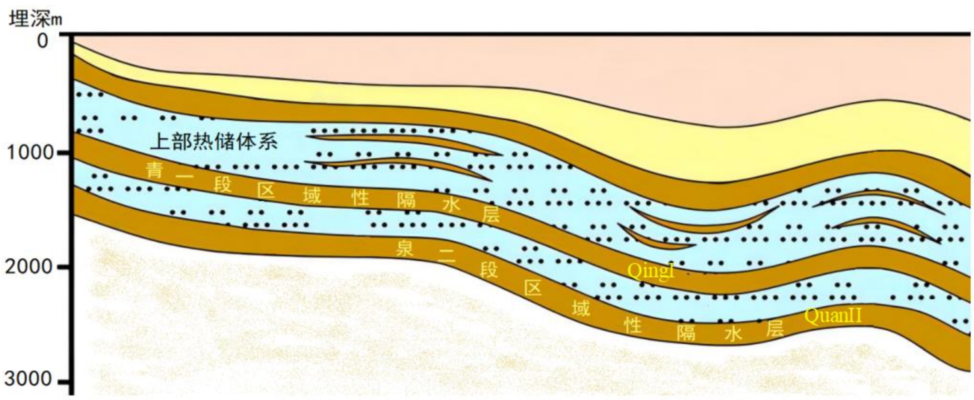

Figure 2-1 Diagram of the cross section of the thermal storage system in the northern Songliao Basin

The scale and development potential of geothermal resources in medium and low permeability reservoirs in the northern Songliao Basin are huge. Developed hydrothermal reservoirs mainly include the Yaojia I and Yaojia II section, the Qingshankou II section, the Quantou III and Quantou IV section.

According to thermal storage thickness, physical properties, temperature and predicted single well productivity, the geothermal favorable areas in the northern Songliao Basin are divided into three categories.

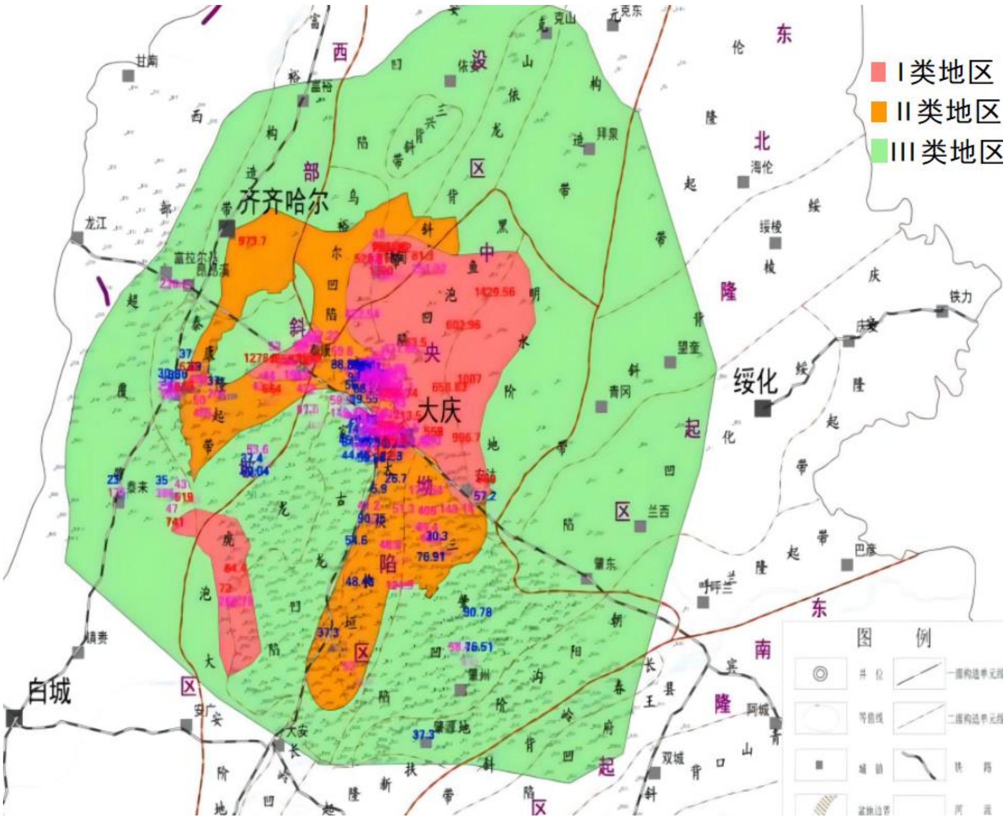

Figure 2-2 Schematic diagram of the distribution of geothermal water in the northern Songliao Basin

In Class I area, the porosity is generally greater than 20%, the air permeability is generally greater than 100mD, the burial depth is generally 1200~1500m, the thickness of the main thermal storage layer is generally greater than 100m, the formation temperature is generally 50~70℃, and the predicted single well productivity is greater than 500m^3/d, up to 1000~1500m^3/d.

In Class II area, the porosity is generally 15%~20%, the air permeability is generally 10~100mD, the burial depth is generally 1200~2000m, the thickness of the main thermal storage layer is generally 50~100m, the formation temperature is generally 50~90℃, and the single well productivity is generally 200 ~500m^3/d, up to 1000m^3/d in dessert areas.

In Class III area, the porosity is generally 5%~10%, the air permeability is generally greater than 1~10mD, the burial depth is generally 1500~2000m, the thickness of the main thermal storage layer is generally less than 50m, the formation temperature is generally 60~90℃, and the single well productivity is generally less than $100m^3/d$.

3 Necessity of replacing industrial using heat test with geothermal water in oil areas

3.1 Using heat in the industrial production is huge

For oilfields located in alpine regions, the climate is cold and long and dry in winter.It becomes from cold and dry to warm and humid in summer[5]. Temperature changes largely. Ice-covered period is long and frost-free period is short. The frozen soil depth is about 2.0-2.2 m. The monthly average minimum temperature is minus 19.3 ℃, the extreme minimum temperature is -36.2 ℃, the monthly average maximum temperature is 25 ℃, and the extreme maximum temperature is 37.4 ℃. The crude oil belongs to the "three high" crude oil with high freezing point, high wax content and high viscosity, which needs to be heated, collected and transported. The comprehensive energy consumption per unit of oilfield crude oil production hit 106.08~140.96kgce/t, as a whole, the production energy consumption is high.

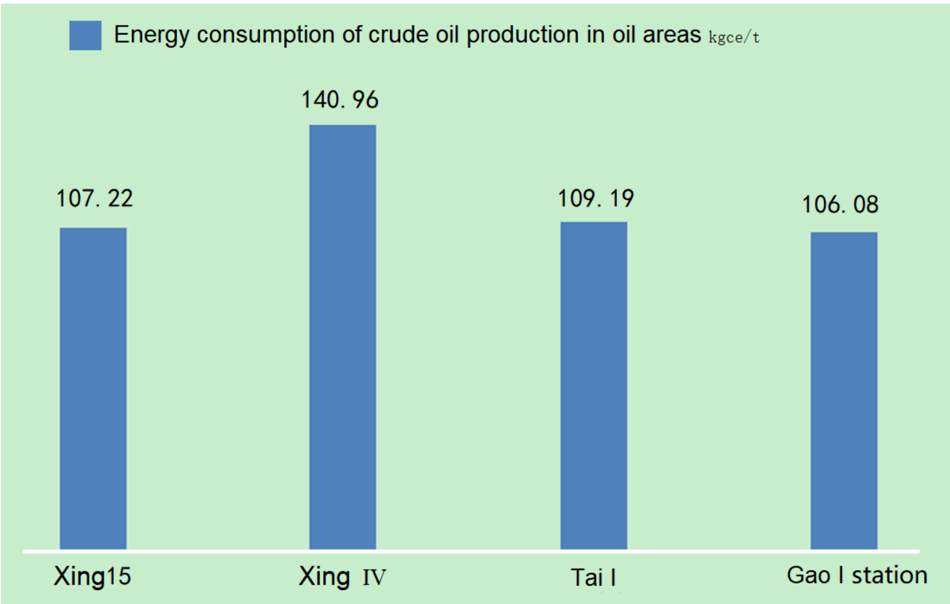

Figure 2-3 Comparison of energy consumption indicators for high water cut integrated oilfields

According to the "14th Five-Year Plan" development plan for oilfields, the total energy consumption in 2025 will reach 6.26 million tons of standard coal. Taking into account the "14th Five-Year" energy-saving arrangement, the total energy consumption is predicted to be 5.89 million tons of standard coal. Therefore, it is of great significance to accelerate the development of geothermal resources and to replace the using heat of surface engineering processes with the geothermal water heating.

3.2 The necessity of carrying out the recharge tests of geothermal water development in oil areas

As a renewable and clean energy, geothermal resources can be developed and utilized economically and effectively, which can effectively improve the energy structure, optimize energy problems, and achieve sustainable economic, social and environmental development [6]. In the early stage of geothermal resource development, due to insufficient understanding, imperfect mining methods, and incomplete development plans, excessive exploitation resulted in shortened thermal storage life, rapid decline in thermal storage water level, and serious waste of geothermal resources. In order to control the drop of water level effectively and protect geothermal resources, geothermal recharge technology came into being.

The purpose of geothermal recharge has three aspects: one is to treat geothermal waste water, the other is to improve or restore the heat production capacity of thermal storage, and the third purpose is to maintain the fluid pressure of thermal storage and maintain mining conditions of geothermal fields. At present, the recharge technology has been popularized and applied worldwide, and it has been widely used in more than ten countries including the United States, New Zealand, Iceland, Italy, France, Japan, Romania, Denmark, Philippines and so on. In China, geothermal recharge technologies in Beijing and Tianjin have also had a good start and achieved good results.

According to the current domestic and foreign examples of recharge, both fissure-karst water-type thermal reservoirs and pore-fissure water-type thermal reservoirs can be reinjected. According to the relative thermal reservoir level of recharge, it can be divided into the same layer recharge and different layers recharge. Since the recharged water flows through different types of thermal reservoirs during different-layers recharge, the water quality will be changed, which may cause water pollution. Therefore, the recharge type is preferred to use the same layer recharge.

Domestic and foreign tests of recharge were all based on experimental researches. Through geothermal tail water recharge experiments, we can understand whether the recharge will block or corrode water-bearing sections, determine the economic feasibility of recharge, and establish refill modes. There isn’t an example of geothermal water recharge project in Songliao Basin. It is necessary to pass recharge tests and long-term monitoring work to avoid resource damage and adverse geological environment problems caused by recharge. Relevant parameters will be determined to select optimal geothermal water favorable areas, and form supporting technologies such as reservoir engineering, water extraction engineering and surface engineering. The above mentioned will provide supports for the scale and further benefit development of geothermal water.

4 Methods for selecting geothermal water development test area

4.1 Selection of the experimental area

The use of abundant geothermal water resources, the use of scrapped oil and water wells for secondary development, and the reuse of idle resources can save a lot of funds required for new geothermal wells, and can shorten the construction period of geothermal wells, consequently that can be beneficial to speeding up the development and utilization of geothermal oil areas. According to the development of geothermal water resources and the distribution of favorable areas in the northern Songliao Basin, the experimental area could be selected in the oil area with relatively great amount of groundwater.

Basic methods for the optimization of the test area: (1) The temperature of the hot water reservoir is high, generally reaching 50~90℃. (2) The cumulative thickness of the thermal reservoir is large, the distribution is stable, the single well productivity is high, and the hot water resources are large. (3) The thermal has good storage properties, the stratum is normal pressure or low pressure, and recharge is easy. (4) The ground in the test area has using heat demands. (5) Abandoned wells are preferentially selected, and a well pattern for production and irrigation can be formed to carry out experiments.

In order to ensure the normal production of the main oil areas of the oilfield, no tests will be carried out in the main oil areas for the time being. The oil layer developed in Qijiabei Oilfield is Fuyu tight oil, and the upper and lower oil layers in the upper Saertu, Putaohua, Gao I and Gao II are all water layers. The characteristics of water production do not affect the oilfield production.

The "extraction and irrigation balance" test area was selected in the Gu 704 well area of Qijiabei Oilfield. This block belongs to the geothermal class II area. Although the thickness and physical properties of the thermal reservoir are slightly lower than those of the main oil production areas, once the recharge test succeeds, areas with better geological conditions than Qijiabei could be promoted and utilized on a large scale.

4.2 Basic conditions of the test area

(1) There is hot water underground

The geothermal gradient in the test area is 4.07° C/100m, and the section temperature is between 74 and 88° C. The area of the test area is $8.39km^2$, the thickness of thermal storage is 56~135m, and the average thickness is about 85m. Recoverable resources are $0.3587\times10^8m^3$ water, $0.0281\times10^{18}J$ thermal energy, equivalent to 97×10^4 tons of standard coal.

The effective porosity of thermal storage is 8~24%, with an average of 15.4%; the air permeability is 0.1~1000mD, with an average of 63.1mD, which belongs to the medium and low permeability reservoir with good physical properties. The pressure coefficient of the main thermal storage section is 1.003, and it has the conditions for low pressure recharge. It is predicted that the three sets of water layers of the SPG will be shot. The flow rate is 42~50 m^3/h, and the production capacity will hit 1009~1219 m^3/d.

(2) Users with useful heat demand on the ground

Oilfield production facilities have been built near the abandoned wells. Qijiabei No. 1 Combined Station has heat demands. The heat loads of equipment such as water-mixed heating furnace, hot water vacuum furnace and heating and dehydration unit are about 4.2~5.4MW.

(3) Abandoned wellbores can be reconstructed

13 abandoned wells were screened, and 7 wells were in good condition, with the well depth of 2275~ 2360m. The depth has exceeded the water intake target layer, and it has the conditions for the utilization of abandoned wells. Use a drillable bridge plug to seal the Fuyu layer and rebuild the artificial bottom. The test could adopt the whole-process integrated sub-injection pipe string to recharge in layers.Use submersible electric pump lifting method to mine geothermal water.

5 Heat planning for ground production process

5.1 Current status of production heat in the test area

Qijiabei No.1 Union Station is a small multi-functional processing station, mainly responsible for the crude oil gathering and transportation, water injection, and power supply tasks in Qijiabei Oilfield. The oil collection system outside the station adopts the large-ring water mixing and oil collection process of "one mixing and multiple returns". This station controls over 432 oil wells. Incoming liquid inlet temperature is controlled at 38~41℃ (the freezing point of crude oil is 38℃) . The exit pressure of mixing water is 2.0MPa . The temperature of mixing water is ≤70℃. Heat load and parameters for production are shown in Table 5-1. The actual heat load is 5.1MW in winter, and the actual heat load is 3.9MW in summer.

Table 5-1 Using heat load table

Heat function	Heating medium	Inlet temperature (℃)	Output temperature (℃)	Actual heat load in winter (MW)	Actual heat load in summer (MW)
Dehydration heating	Produced fluid	40	50	0.3	0.3
Gathering and transportation mixed with water heating	Produced water	40	70	4.0	3.3

Heating& heat tracing	Clear water	50	70	0.8	0.3
total				5.1	3.9

5.2 Using heat replacing traditional process route

Using heat is to use one of the three methods of heat conduction, heat convection, and heat radiation, or a combination of several styles, to provide heat and maintain a thermal environment[7].

The hot water produced from underground will be used to extract geothermal energy through indirect heat exchange, which is used to increase the temperature of the incoming liquid from oil wells and reduce the consumption of natural gas. The geothermal water produced by the heating well extracts geothermal energy through indirect heat exchange. After the geothermal water is de-sanded, it will be sent to the Qijiabei No.1 Union Station to be heated by a heat exchanger to increase the temperature of the incoming liquid from oil wells in the station. The geothermal water after heat exchange is filtered and recharged to recharge wells. The process technology route map is shown in Figure 5-1.

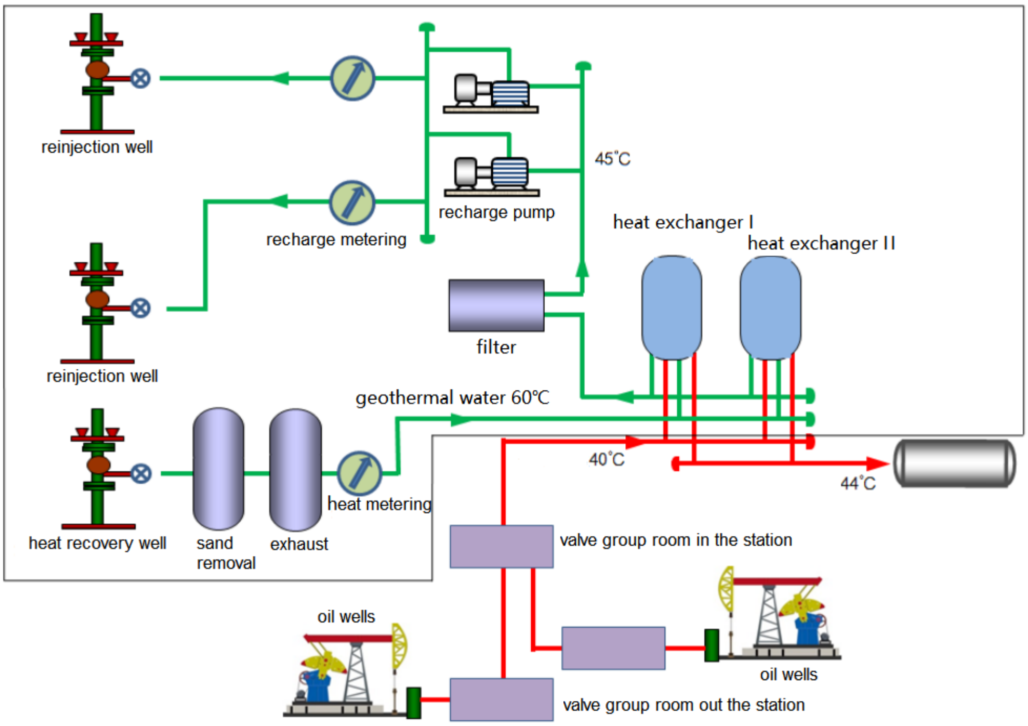

Figure 5-1 Process technology route map

5.3 Process design and selection of processing equipment

(1) Geothermal water system

The hot water at 60° C at the outlet of the heat production well will be supplied to the new heat exchangers in the Qijiabei No.1 Union Station through the geothermal water pipe network outside the station after sand removal, exhaust and metering. After heating the process medium in the station, the temperature of the geothermal water will drop. When the temperature reaches 45°C, it will be filtered by a filter device until the water quality reaches the recharge requirement (3~5 μm), and then be pressurized to 2.0MPa by a booster pump, afterwards through the geothermal water pipe network out the station sent to the recharge well. The geothermal water is set up with two-stage filtration, firstly filtered by the primary filter until the water quality reaches 10~50 μm, and then filtered by the high-efficiency filter until the water quality reaches 3~5 μm.

(2) Process medium heat exchange system

The liquid coming from 40℃ oil wells from the valve group in the station is first heated by the heat exchanger, and then heated to 44℃, and then heated by the four-in-one treatment equipment. And since the incoming liquid is a kind of three-phase medium of oil, gas and water, in order to ensure the fluidity, two shell-and-tube heat exchangers are selected, and a single heat exchanger with a heat exchange load of 1.0MW is used. The liquid from the oil well goes through the tube side, and the geothermal water goes through the shell side.

5.4 Energy saving effect

The field test of extraction and irrigation of geothermal wells could be operated in the mode of "1 extraction and 2 irrigation". The annual natural gas saving value would hit $81.1\times10^4m^3$, which is equivalent to 984.8 tons of standard coal, and the effect of energy saving and emission reduction is remarkable.

6 Analysis Conclusion

The total amount of geothermal energy resources in the northern Songliao Basin is large and there are many types. The development and utilization of geothermal energy is a major measure to implement the green and low-carbon development strategy. The overall deployment of geothermal engineering is to break through the development technology of middle-shallow geothermal water and middle-deep geothermal energy, and reserve hot dry rock power generation technology. Design planning might dedicates to construct the middle-shallow geothermal water test areas and the middle-deep geothermal energy test areas, and improving the technical scheme and process gradually. U-shaped recharge or hot oil co-production tests could be carried out, and supporting the surface engineering construction. Ground-source heat pump technology could optimize design to improve the performance of heat pump coefficient, use more effective liquid working fluid, and improve the efficiency of auxiliary equipment such as fans [8].Through the development and utilization of large-scale geothermal water, achieve clean resource replacement, give impetus to carbon emission reduction and carbon neutrality.

References

[1] Zheng Ren-rui, Zhou Ping, Tang Jin-rong；Exploitation and utilization of geothermal resources in Europe and its enlightenment [J]; China Ming Magazine; 2017,5:Vol. 26, no. 5

[2] Joint Research Center. 2015 JRC geothermal energy Status Report [R/OL]; (2016-02-25)[2016-09-20]

[3] Hu Xia；Distribution Characteristics of Favorable Thermal Storage Areas in the Northern Songliao Basin[J]; Western Prospecting Project; 2016,3:33-34

[4] Massachusetts Institute of Technology. The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on The United States in The 21st century [R] . Boston, : Massachusetts Institute of Technology, 2006.

[5] Hou Yiling； A Preliminary Study on Climate Change and Its Causes in Northeast China and Its Adjacent Regions[D]; Institute of Cold and Arid Regions, Chinese Academy of Sciences; 2006,5:38-39

[6] Wang Wei；Research on the Development, Utilization and Sustainable Development of Geothermal Resources[J]; Grassroots Construction; 2017,12(26)

[7] Yang Yuefei；Research on Application Technology of Gas Radiant Heating System [D]; Daqing Petroleum Institute; 2007

[8] European Commission. 2013 Technology Map of the European Strategic Energy Technology Plan [R/OL] . (2014-05)[2016-11-20]