Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

Feasibility Study on Geothermal Large-scale Development in Yutai County, Shandong, China

Xuezhong Zhu[1], Kang Zhou[2], Yuanqiang Zhao[3], Hulong Wang[4] and Jiaxing Zhu[1]

[1]Hongmeng Energy (Shandong) Co., Ltd. Jining, Shandong 272119

[2]State Key Laboratory of Clean Energy Utilization Zhejiang University, Hangzhou, Zhejiang 310058

[3]The Second Exploration Team of Shandong Coal Geology Bureau, Xuzhou, Jiangsu 221000

[4]Xuzhou Zhongkuang Kairui Science and Technology Co. Led., Xuzhou, Jiangsu 221000

13905471968@139.com

Keywords: geothermal, feasibility study, large-scale development, district heating, dehydration and drying, subsurface heat storage, industrial steam, Yutai county

ABSTRACT

There are 653 km^2 of land area in Yutai county, Shandong province, China. Even no geothermal exploration was carried out locally, there are rich data for subsurface geological structure from coal mining at adjoining areas. Jurassic-Cretaceous and Permian systems with covered Quaternary deposits form good caprock. It made the fracture and karst limestone of Cambrian and Ordovician systems to be ideal reservoir at about 2,000 m depth. A geothermal well drilled 2,309 m in depth and yielded 68 .5℃ thermal water. The temperature of well bottom in Ordovician limestone reservoir is 74.5℃. So local geothermal gradient is 2.62℃/100m. It could be intended that the Cambrian limestone reservoir would yield geothermal water in higher temperature. Those potential reservoirs distributed in most part of the county underground. Such geothermal resources could be explored and developed in large-scale size. Exploited geothermal water could be used in district heating to replace existing coal boiler heating in county town. And local main specialty crop pepper could use geothermal for dehydration and drying in summer-autumn. Supplementary measure has also considered that using ground source heat pump and subsurface heat storage by electric heating from wind power and solar PV. In addition, the technique of using electromagnetic induction heating to produce industrial steam would save rather electricity and cost. All these will be great support for local government's work program on reducing coal consumption. Geothermal development will contribute a result to much reduce carbon dioxide emission and improve environment. And it will create a new geothermal industry and gain remarkable economic benefits.

1. INTRODUCTION

The president Xijin Ping has made the solemn announcement in the 75th United Nations Congress that China will realize its goal of carbon peak in 2030, and carbon neutrality in 2060. The essential steps of moving towards a low carbon society is energy transformation from conventional fossil fuel energy to the renewable. In 2019, China's non-fossil energy accounted for 15.3% of the total energy consumption, which needs to reach 25% by 2030 and 60% by 2050. President Xi pointed out in his speech that "Party committees and governments at all levels should come up with timetables, road maps and "construction drawings" to achieve carbon peak and carbon neutrality, and should resolutely take down projects with high energy consumption or having large carbon emissions that do not meet the requirements."

The government of Jining City at all levels, and related entities and enterprises in Shandong Province have actively responded to the announcement and are busy in coming up with strategies and elaborate plans. Jining City originally has a coal field area of 3,920 km^2, and an estimated coal capacity of 15.158 billion tons. Currently it has a yearly capacity of producing coal 60 million tons. As a response to the national call, Jining City has made the proposal "About the work of cutting down coal consumption in Jining (2020-2021)". Yutai County with a total area of 653km^2, has occupied one sixth of the land of Jining City, so what measures should be taken to contribute to reducing coal consumption?

To comply with the Carbon Neutrality Act made by the government, Hongmeng Energy (Shandong) Co., Ltd. has drafted the compilation of "The very first step toward geothermal heating and comprehensive utilization for agriculture and industries from deep geothermal as to replace coal fired boilers." These actions tap into its own advantages to foster development of the company, and made the suggestions on exploitation in the geothermal resources in Yutai County so as to reduce the coal consumption and contribute to the development of clean energy. As a step forward, the company also devised "Feasibility study on scaled-up exploitation of Yutai geothermal energy" in detail, with a practical approach to explore geothermal resources followed by exploitation, which is expected to fully utilize the benefits of low-to-medium temperature geothermal resources in the county to realize a scaled development. The geothermal wells after completion serve as the heat supply for 2 million square meters area during winter while assist in the manufacturing of local agricultural products such as dried peppers. The enthalpy of geothermal water thus produced will be upgraded further by means of electromagnetic techniques developed by the company, thereby supplying steam for particular industries. These three aspects constitute the main approach that fully exhaust the geothermal resources available. On the other hand, geothermal resources can be used up. And two backup strategies have been planned: 1. resorting to ground-source heat pump to increase heat supply instead; 2. applying the high temperature thermal storage strategy using the wasted solar and wind power. The later one is about to be tested and integrated into the system.

2. THE REGIONAL GEOLOGICAL BACKGROUND OF YUTAI COUNTY

Geologically speaking, Yutai County belongs to the West Shandong uplift（II）, the North China tectonic region. More elaborately, it is within Yutai hidden depression (II_{b1}^{12}) pertaining to Heze-Yanzhou hidden faulting uplift (II_{b1}), which is located in South-West Shandong hidden uplift (II_b) (Figure 1).

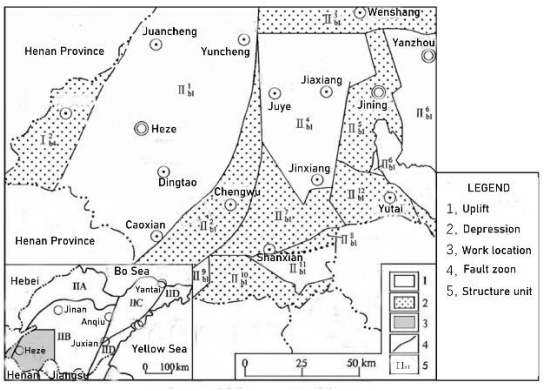

Figure 1: Tectonic division of west-south Shandong province

This region mainly comprises two normal faults, trending near south-north and near east-west. East-west trending fracture forms prior to the south-north fracture does, and was cut by the latter. Due to the cutting movement of the two faults, shallow depression and uplift regions were produced in south-west Shandong province: depressions including Yutai hidden depression, Shizhai hidden depression, Huankou hidden depression, Jining idden depression, Jinxiang hidden depression, Shilou hidden depression, Tengzhou hidden depression, and Huanggang hidden depression, while uplifts including Jiaxiang uplift, Yanzhou hidden uplifts and Longwang Temple hidden lift (Figure 2).

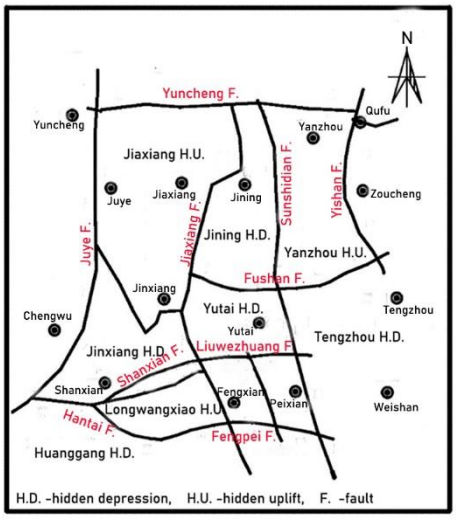

Figure 2: Sketch map showing regional geological structure

Yutai hidden depression contains a basin faulting at northern side, forming a subducted region with its southern side covered, and is connected with two sags, namely, Shizhai and Huankou in Jiangsu province. Western and Eastern boundaries of the basin are bordered by Jiaxiang fault and Sunshidian Fault. While its northern boundary and southern boundary are bordered by Fushan Fault and Shanxian Fault, respectively, depicting the block to be higher at the Southern and Eastern sides.

A large area of the basement rock saturated with water was found in Yutai County based on such geological background. The structure contains the potential geothermal reservoir with abundant low-to-medium temperature geothermal resources available for further scale-up exploitation.

3. GEOTHERMAL RESOURCE POTENTIAL

3.1 Potential of Deep Stratified Geothermal Reservoir of Large Sedimentary Basin

The locality of Yutai County sits within the Jining Basin, a hydrothermal tectonic basin geologically pertaining to the Jining Depression. Beneath the caprock of Jurassic (J) and Permian (P) origin, geothermal water saturates in karst cracks and caverns of Cambrian and Ordovician (∈+O) limestone, thus bearing a huge stratified of geothermal resources, and can be made available by drilling to the correspondent depth, as can been seen from the basement rock geological map (Figure 3).

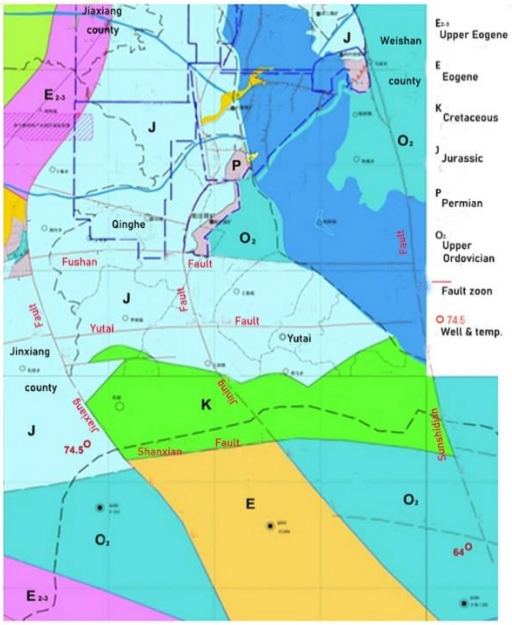

Figure 3: Basement rock geological map of Yutai region

3.2 The Pattern Depicted by Geological Tectonics

From the past exploitation of coal bed in Yutai County and the adjacency has yielded much more fruitful, more elaborate and more reliable results over the geological structure beneath the ground than the current survey aiming for geothermal resources, a realistic merit for geothermal exploitation saving much of the time and budget to gather crucial firsthand information which would have been needed for a raw target.

It can be seen from the geological map of the basement rock for Yutai County subsurface formation are of the Ordovician Majiagou group, constituting a crack-filled Karst (Carbonate) geothermal reservoir. It is covered by extremely thick Jurassic and Permian. At the South of the county caprocks of Cretaceous and Paleogene System are found, constituting a entire caprock structure for the reservoir.

3.3 Completed Geothermal Wells Readily Available

In the year 2019 a geothermal well 23.5km Southwest of the county has been drilled and completed in Boqiao, Yucheng Town at 2,309 m depth. Limestones of Majiagou Formation of Ordovician system were found to be with good water permeability and is saturated with water. The downhole temperature of the well is 74.5°C, and water temperature at the wellhead is 68.5°C. Using the data from the well one can establish a simple calculation: Set the regular annual average temperature at 15 m depth as 14.4 °C. Temperature difference across 2,294 m depth is 60.1°C (74.5-14.4). Thus the local geothermal gradient can be obtained: 60.1/2,294=2.62°C/100m.

In the year 2021, another hydrothermal well was drilled and completed at 2,200m depth in Anguo Town area, Pei County in Jiangsu Province located 29 km Southeast of Yutai County, which adjoins Yutai County from the South. Water temperature at the wellhead is 65°C, and water flow rate is 1,940 m^3/d. The downhole temperature of the borehole is estimated to be 71°C. And the geothermal gradient is estimated to be (71-14.4)/(2,200-15)=2.59°C /100m, approximately the same as that of the Yutai County.

These findings indicate that within Yutai hidden Depression, geological conditions are all similar: as long as drilling to the required depth where the stratified geothermal reservoir is located, fulfilled geothermal wellbore can be completed. The above overlaying Ordovician system is roughly 1,000 m thick, beneath which Cambrian limestone layer extends to another 500m. Except for minor shale the system is made entirely from porous Karstic geothermal reservoir. Roughly 15 to 20°C temperature increase can be expected, yielding a final downhole temperature around 80°C.

The potential geothermal resources if confirmed by primary on-site survey, are readily to be exploited in a fashion where the ongoing survey and exploitation can be implemented side by side, so that a rapid, scaled-up development can be realized.

4. GEOTHERMAL ENERGY FOR HEATING AND FOR COMPREHENSIVE USE IN AGRICULTURE AND INDUSTRY

Geothermal resources can play a significant role in Yutai County's development, due to its gigantic distribution of its stratified geothermal reservoir, being capable of perform large scale exploitation.

4.1 District Heating Use in the Winter

Currently, 2 million square-meter building area is to be equipped with district heating, and it will increase to 3 or even 5 million square meters. Simplest plan would be made if coal could be used to supply the heat. However, heating from geothermal energy is the best substitute at the contemporary trend of cutting down coal consumption.

The heating load depends on the entire constructed area. Assuming that the unit heating load being 40W/m^2, the heating load for the total Yutai county area would be 80MWt.

When the wellhead temperature reaches 80°C, its temperature may drop to 35°C after being used. Given the flow rate of the production well 100m^3/h, the power output of a single well would be 5.23MWt. 15.3 wells would be needed to accommodate the heat load of the district. If re-injection is further considered, 30 wells are required to fulfill the heat load. Yet if 2 wells for production and one well for re-injection, 23 wells would be needed. These work load constitute the 1st stage of Yutai engineering project. As for 300 km^2, the planned wells have a loosened distribution since each well will take care of more than 10km^2 land area.

Yutai county has a total area of 653km^2. Even if the heating area is planned to increase from 300 km^2 to 400 km^2, the density for well distribution is still compatible with the increased scope of heating.

The scale of district heating from geothermal energy in China has topped the list among the globe. Commonly used methods include constructing heating stations. Tianjin has made the record of utilizing geothermal heating stations. In the year 2020, 38.4 million m^2 area has been supplied with geothermal heat. Tianjin Haihe Xintiandi community, having a total area of 0.235 million m^2 supplied with geothermal energy, had received salient attention and positive feedback from both domestic and abroad attendees in the Workshop on Direct Use of Geothermal Resources in Asia in 2008, in a collaboration of China and Iceland (Figure 4). In Xiong County, Hebei Province, the smokeless city, a total area of 4 million m^2 has realized the district heating in 2012, thereby forging a Xiong County Mode which becomes a prototype of application in heating station and re-injection operation. These typical successful demonstrations, has given credits to direct heat use as a mature technology.

Figure 4: Domestic and abroad experts visit in Tianjin geothermal heating station

4.2 Pepper Drying-for the Local Specialty

About 40,000 hectares of land is occupied for peppers to grow in Yutai County and adjoining areas. More than 20 pepper dehydration factories have been built, forming a scaled chain of industry including the plantation, purchasing, dehydration, OEM, storage and selling. The local planting area for peppers prepared for dehydration in Yucheng Town is 3,300 hectares, with a total weight of more than 0.1 million tons. The cost for dehydration for a single ton of peppers is 1,800 RMB, which can be reduced to 800 RMB if geothermal water dehydration and electrical heating are involved. A pilot dehydration plant is proposed, with a retrofitted, upgraded dehydration-drying production line for the initiation of the demonstration project, after which the same strategy will be applied elsewhere.

4.3 Supply of Industrial Steam

It is proposed that part of the geothermal water is utilized through a electromagnetic heating technology owned by the company, in steam supply produced at a rate of 50 t/h. The steam with sufficiently high temperature and pressure would serve the economical developing district in the western city, with a cost of 160 RMB/t. In contrast, the price sold to the buyers is 260 RMB/t, leaving decent profit for the producers.

4.4 Backup Systems

Backup systems have also been proposed, as a necessity to ensure a safe running of the entire system even if geothermal resources are overused.

4.4.1 Surface Water Ground Source Heat Pump

Weishan lake forms an oblique trending across the north County. It is 32 km long within the county and has an area of 19.84 km^2. The temperature at the bottom of the lake is around 14.9 to 16.0 degree Celsius during Winter. A large scale power station or plant running on water source heat pump can be built to utilize the water to supply heat to satisfy the heating and cooling load of the residential and public buildings in Binhu New District.

4.4.2 Technology of Dynamic Energy Storage

In order to balance the heat load during the coldest months in winter, some thermal energy storage devices have been design by the company: the underground thermal storage media can be heated to 600 °C by the low quality electricity produced by solar panels and wind turbines. The heat transmission fluid enters the heat exchanger of the thermal storage media as pure water and becomes high temperature, low pressure steam-water mixture ready to be used.

4.5 Scale Effect / Size Effect

The first stage exploitation of Yutai County geothermal resources, if concerned with 2 million square meters, has a capacity of 80 MWt, which is considered to be "large scale" according to the GB/T11615-2010, the national "Geological Exploration Standard of Geothermal Resource". Hence the term "large scale exploitation" was added to the title. Besides, geothermal water was used for district heating in winter, and dehydration of peppers in summer, while affordable/profitable steam can be extracted therein. Thus, the large scale reflects not only its capacity, but also its coefficient of utilization, since it will be in use during most of days in a year.

5. ARRANGEMENT OF THE FEASIBILITY STUDY

A more elaborate plan for the feasibility study will follow the guideline of "combined exploration plus exploitation". As long as the basic grasp of the geological conditions are ensured, the progress of exploitation can be made faster. For example, the first test bore drilled in the pilot project can be perfected to be a completed production well, ready for soon use.

5.1 Geophysical Exploration and Verification

The current data obtained is of less precision for laying out the geothermal wells, which is compatible only for the stage of prefeasibility study. Geophysical exploration is among the most important measures that can be implemented at this stage. Explorations through long section and to sufficient depth with high precision is required so as to fain an insight of the geological structures and layout, mainly of the resource distribution of the stratiform reservoir, and of occurance control of fault zone. Then first well site could be selected for drilling.

As for geothermal exploration in terms of geophysics, two approaches are most commonly used, i.e., MT and CSAMT. Although they are sensitive and precise in terms of explaining/recognizing faults/fault zones/crack development. They pale when it comes to the recognition of the division of stratified formation. A more advanced approach, the so called WFEM (wide field electro-magnetic method) developed by Academician Jishan He, has received noticeable credibility in recent years. It is capable of detecting depth up to 5,000 m while giving the info. including locations and temperature of geothermal reservoir and caprock, which will be applied in the project.

2 East-west long sections and 2 south-north short sections were planned as to the implementation of WFFM in respect to the geothermal resource exploration in Yutai County. 2 east-west sections are planned at the northern and southern side of Yutai Fault, which cut through the south-north trending Jining Fault that lays in the middle of the Yutai hidden depression. And they extend further to the west bound of the hidden depression, i.e., the Jiaxiang fault zone. Both of the sections are 30km long. Similarly, the two south-north sections approximately 15km long, respectively are distributed at the west and east side (Figure 5). In total, there are 4 sections having a total length of 90km to be explored at the stage, so as to find out the general arrangement of the geothermal reservoir. Then drillings can be planned accordingly.

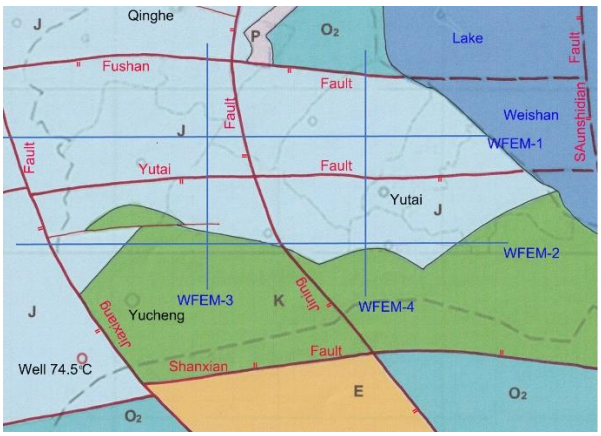

Figure 5: Map showing geophysical work layout for geothermal feasibility survey in Yutai

5.2 Geochemistry Research for Improvement of the Project

It is strongly suggested to take on a full analysis in the water samples collected from completed geothermal wells. And then conduct verification towards subsurface temperature, permeability, water-rock equilibrium interaction and other characteristics/attributes representing the reservoir. At the meantime, geothermal water is analyzed based on stable isotopes of Deuterium and ^{18}O. While the dating of geothermal water is gathered through the analysis of radioactive isotopes Tritium and ^{14}C. Geochemistry research is also employed to completed geothermal wells/boreholes after on-site survey, so as to gain a better understanding to the features of the geothermal reservoir and those of the geothermal fluid.

5.3 Combined Effort of Geothermal Resource Exploration, Demonstration and Utilization

The primary location for test bore and geothermal energy production is suggested, at the lower part of the crossing point of Yutai fault and Jining fault, i.e., the southwest part of the crossing point, where the most promising spot in the reservoir is found based on the known conditions of the geological structure, giving an ideal spot for the first demonstration project of heating station in Yutai.

ACKNOWLEDGEMENTS

There are many who have offer guidance and help to us in planning, design and compilation of the work for the project, and to whom thanks are due: Jiwen Teng, academician of China Academy of Science, doctoral advisor of Geology and Geophysics Institute of China Academy of Science, Qingxiang Zhuang, direct of the Energy Research Association of Fujian Province and Chief Engineer of Fujian Xianghe Geothermal Exploitation Co., Ltd., and Keyan Zheng, former chairman of Geothermal Council of China Energy Society, chairman of expert group of Geothermal Industry Working Committee of China Technical Supervision and Information Association.

REFERENCES

Shandong provincial Jining municipal government: Work program on reducing coal consumption in Jining city (2020-2021). (2019).

Hongmeng Energy (Shandong) Co. Ltd.: Preliminary scheme on deep geothermal replaced coal burning boiler for district heating and industrial and agricultural comprehensive use. (2021).

He, J.: New progress of frequency domain electrical method. *Progress of Geophysics*, **22(4)**, (2007).

Stefaniuk, M. et. al.: Application of Geophysical Methods for the Recognition of Geothermal Reservoirs Parameters in Poland. *Proceedings* of WGC2020, Reykjavík, Iceland, (2021).

Rahadinata, T. et. al.: Investigation of Geothermal Structures of the Kadidia Area, Indonesia, using the Magnetotelluric Method. *Proceedings* of WGC2015. Melbourne, Australia, (2015).

Lashin, A. et. al.: Geophysical Exploration of the Western Saudi Arabian Geothermal Province: First Results from the Al-Lith Area. *Proceedings* of WGC2015. Melbourne, Australia, (2015).

Chen, Z. et. al.: Discovering blind geothermal resources by exploring buried fault –a case study for geothermal drilling in Mukeng, China. *Proceedings* of AGS 11. Chiengmai, Thailand, (2016).