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GEOTHERMAL RESOURCES DEVELOPMENT AND UTILIZATION IN DAQING ZONE

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ABSTRACT

After more than ten years of exploration, Daqing, where contains abundant geothermal resources, is determined primarily that there is $4.923\times10^{11}m^3$ geothermal water hidden in the buried depth of less than 2,000m in Yaojia Formation, Qingshankou Formation and Quantou Formation, which is equivalent to 3.5×10^8t heat provided by standard coal. Since 1998, four large water-heat geothermal fields have been found. Their names are Lindian, Dumeng, Dongfeng and Rangxi. More than 30 new geothermal wells were drilled and 15 oil and gas exploration wells were reformed. Well-capacity of heat water reaches 300~2,500m^3 per day, based on NaHCO3 water type. Well head temperature is 45℃ ~80℃. And the heat water, with high salinity of 2,000mg/L~10,000mg/L, is rich in iodine, fluorine, bromine and many other trace elements as well as a lot of essential ions, therefore, it is considered to be with high medical value. For now, the four geothermal fields have already been successfully developed and utilized, getting considerable economic, social and environmental benefits in tourism, heating, and bathing, recuperation, planting, breeding, and so on. Daqing has become a well-known "China spa town", meanwhile, geothermal resources have also become an important city card of Daqing.

KEY WORDS:
Daqing, geothermal resources, geothermal field, sedimentation basin

GENERAL INSTRUCTIONS

With the extensive use of traditional fossil energy sources, energy exhaustion and the worsening climate have been the two headaches of human social development (Rachman, 2007). Promoting the development of green, low-carbon renewable energy becomes an important solution to the two problems (Wang Guolian, 2011). Geothermal resources, due to its properties of richness, renewability, reliability and environmental acceptability, has a wide range world market and proves to be the most realistic and competitive energy in the new energy family (Lund, 2005; Lund et al., 2008).

Daqing oilfield, rich in petroleum resources, is China's largest oil and gas production base as well as one of the world's 11 giant oilfields whose total oil production is over one billion tons. As far back as 1970s, geothermal water was found in a few exploration wells. The temperature could reach 40 ℃ and the natural daily overflow could amount to 500 m^3/d (Wang Yafeng, 2003; Yang Mingqian and Liu Qing, 2000). But it wasn't given much attention by people. As Daqing oilfield has come into high containing water exploitation period, difficulties in oil and gas production are increasing. Meanwhile, the capacity is decreasing day by day. Daqing, a city built and being prosperous on the basis of oil, begins to pay attention to issues of energy substitutions. In the year of 1997, Daqing Petroleum Institute (now renamed the Northeast Petroleum University) was invited by Daqing Municipal Government to start the research and exploration on the potential and distribution of its geothermal resources. After ten years' study and practice, the development of geothermal resources has seen a breakthrough. It paves a new way for Daqing's sustainable economic development and shows a huge development potential.

GEOLOGICAL BACKGROUND AND POTENTIAL OF GEOTHERMAL RESOURCES

The exploration of Daqing oilfield shows that Songliao Basin, where Daqing is located in, is a typical continental margin rift basin. Its crust is thin, known as one of the thinnest among the inland basin's crusts in China. The Moho of the entire basin is closed by the 33km depth contour lines, generally in the depth of 29-33km. Daqing is located on the mantle bulge of the basin, deep fault well developed. A low-speed and high-conductivity layer existing in the middle crust of this region, in the depth of 15-25km, is an advantage of a relatively high geothermal

field (Cheng Xueru, 1987; Liu Hefu, 1992, 1996; Tong Chongguang, 1982; Wu Zhenming et al., 1985). Geothermal gradient is an important indicator of basin geothermal field characteristics. High geothermal gradient is the feature of Songliao Basin geothermal field, an average of 3.3℃/100m (Figure 1 & Figure 2). Geothermal gradient in Daqing ranges from 3℃/100m to 6℃/100m in horizon, most parts varying between 4℃/100m and 5℃/100m. In terms of distribution areas, the geothermal gradient is higher in central Daqing Placanticline Structural Belt, in the north of Lindian and Duerbote Mongolian Autonomous County and in the south of Zhaozhou, most of which reaches 4℃/100m, much higher than the global average geothermal gradient 3℃/100m. These fully demonstrate that Daqing has a good background of the geothermal field in forming geothermal resources.

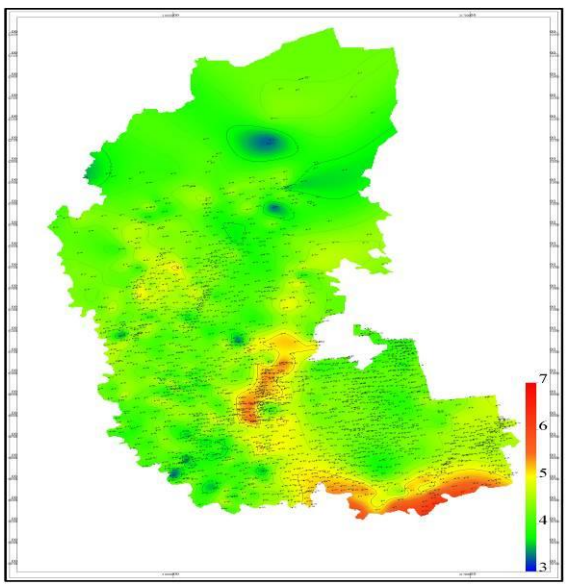

Figure 1: Geothermal gradient of Daqing

Faulting period, the period transformed from fault depression to sag and the depression period took place during the long-term process of evolution in Songliao Basin. Starting from the Middle and Late Jurassic, thousands of meters sediments were deposited in Jurassic and Cretaceous. Among them, Cretaceous strata are relatively shallower, widely distributed with large thickness, rich in oil and gas reserves, with deepening research and full of available information (Zhi-qiang et al., 2010). The drilling data shows that the sandstone is well developed in the Cretaceous Quan3 and Quan4 Member, Qing2 and Qing3 Member as well as Yao1, Yao2 and Yao3 Member of the study area. The sandstone, buried in the depth of 1,000-2,000m with high temperature, turns out to be ideal geothermal reservoirs.

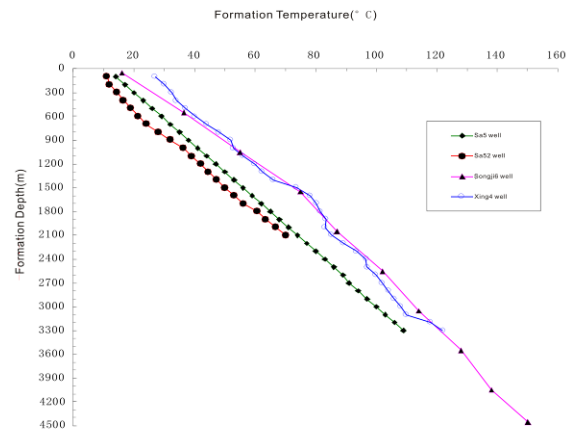

Figure 2: The relation of some exploration wells formation temperature and depth in Daqing

The three geothermal reservoirs are dominated by river deltas. The porosity ranges from 25% to 35%. The permeability varies between $400\times10^{-3}um^2$ and $500\times10^{-3}um^2$, some of them can get to 1,000-$2,000\times10^{-3}um^2$. The thickness of single layer is up to 15-20m, generally 2-5m. The total thickness of the sandstone can reach 200-300m, widely distributed. The framework grains of these geothermal reservoirs are mainly composed of quartz, feldspar and debris. Their contents have no much difference in each layers, with quartz content of 22-37%, feldspar content of 26-41% and debris content of 15-38%. As lithic arkoses, matrix content is generally less than 10%. Silt sandstone structure, medium-grained sandstone structure and part of the fine-grained sandstone structure are the predominant patterns. The major cements are clay minerals and calcite. The sandstones are middling to fine in separation and have favorable physical properties, all of which will help the preservation of geothermal resources.

The upper part of Quan2 Member, Qing1 Member and Nen1 Member mainly are semi-deep and deep lake facies, which were formed at the maximum subsidence period. The deposition is stable. The mudstone is pure, thick, widely distributed and good capping. Therefore, they are good regional water-resisting layers. According to this, the geothermal reservoirs can be divided into two sets of heat reservoir system: the upper one and the lower one (Figure 3). The lower heat reservoir system is made up of Quan3 and Quan4 Member, depth of 1,479.0-2,389.0m with formation temperature of 54-92℃; The upper one is made up of Qing2, Qing3 Member and Yaojia Formation, deep buried (top surface depth of 835.4-1,947.0m), bed thickness of 237.0-448.0m with formation temperature of 42-82℃.

Using volumetric methods and parameters, such as the effective porosity, the sandstone thickness, the reservoir temperature getting from oilfield drilling data, we can get the total reserves of geothermal water of $4.920\times10^{11}m^3$, including that in the three sets of geothermal reservoirs of the four geothermal fields above. If the temperature of tail water is 25℃, the heat containing in the three sets of heat reservoirs is 1.0245×10^{18}J, equivalent to 3.5 billion tons of standard coal. The reserves are very substantial.

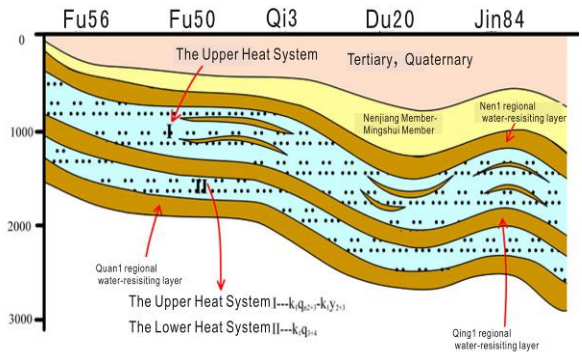

Figure 3: Geothermal reservoir system of Daqing

GEOTHERMAL RESOURCES EXPLORATION AND ITS CHARACTERISTICS

Because the geothermal reservoirs are in the same layer as oil and gas reservoirs, so in order not to affect oil and gas production, Daqing decided to start the research and exploration of geothermal resources in Lindian, a county far from hydrocarbon-generation area. In 1997, at the invitation of Daqing Municipal Government, Northeast Petroleum University made a study on geothermal resource potential and distribution rules in Lindian by taking advantage of gravity, magnetic and electrical data as well as oilfield drilling information. In 1998, the first geothermal well was successfully drilled in Lindian and the hot water production was at $2,200m^3$ per day. From then on, Daqing Municipal Government and Daqing Oilfield devote great efforts to boost the geothermal resource exploration and development. Up to now, 27 geothermal wells have been successfully drilled. Meanwhile, four large and medium-sized geothermal fields were found. They are Lindian Geothermal Field, Dumeng Geothermal Field, Dongxindi Geothermal Field and Rangxi Geothermal Field.

Lindian Geothermal Field is located in the North Plunge Zone of Songliao Basin, an area of 4,000-$5,000km^2$. The total amount of its geothermal water is expected to 180 billion cubic meters. Daily production per well is $2,000\text{-}3,000m^3$ and the temperature is 50-60℃; Dumeng Geothermal Field, an area of $3,000\text{-}4,000km^2$, is located in the Western Slope Zones, west of Qijia Gulong Depression. It covers the western and northern part of Duerbote. The total amount of its geothermal water is expected to 80 billion cubic meters. The total thickness of the heat reservoir is 100-150m. Daily production per well is $1,000\text{-}1,500m^3$ and the temperature is 45-55℃; Dongxindi Geothermal Field is located in the east of Saertu Oilfield and northeast of Dongfengxincun, covering an area of $1,000km^2$. Its geothermal reservoir is thin, with a total thickness of 50-100m. The total amount of its geothermal water is expected to 40-60 billion cubic meters. Daily production per well is $400\text{-}1,000m^3$ and the wellhead temperature is 52-62℃; Rangxin Geothermal Field, an area of 600 km^2, is located in the east of Qijia Gulong Depression and west of LaSaXing Oilfield. The major producing beds of geothermal water are Yao1, Qing2, Qing3 Member, followed by Quan3 and Quan4 Member. The geothermal reservoir is thin, with a total thickness of 50-80m. The total amount of its geothermal water is expected to 30-50 billion cubic meters. Daily production per well is $400\text{-}700m^3$ and the wellhead temperature is 45-65℃.

The type of geothermal water was found to be $NaHCO_3$ by water quality analysis. Cations generally contain K^+, Na^+, Ca^{2+}, Mg^{4+}, F^{2+}, F^{3+}, etc., and anions generally contain HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, F^-, Br^-, I^-, etc. There are more than twenty kinds of trace elements, such as lithium, strontium, zinc, selenium, copper, cadmium and so on. Besides, CH_4, CO_2, O_2, N_2 are found in the water of many wells. The content of CH_4 is higher, being the main gases dissolved in geothermal water. The content of metasilicic acid is usually high, about 32-35mg/L. The content of some trace elements is also high, for example, lithium, strontium, iodine can meet the standard of potable natural mineral water requirements.

DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES

Since the first geothermal well was drilled, Daqing has completed drilling of 8 new geothermal wells and transformation of 13 oil and gas exploration wells. Geothermal development has been utilized in multiple fields, for instance, heating, hot spring, bathing, rehabilitation, mineral water production, cultivation, hotels and swimming. It brings significant economic and social effects.

In terms of geothermal heating, Lindian has established demonstration zones, achievable 540,000 square metres of space heating. And it has heated for nearly 5,000 homes and provided hot water for more than 8,000 households. In the way of bathing and rehabilitation, more than ten upscale clubs has been built in Lindian, Duerbote and the downtown. The number of annual custom reception exceeds a few millions. One sanatorium was built for effective treatment of rheumatism, rheumatoid, cardiovascular

diseases, skin diseases, mental pain, neurasthenia, etc. Approximately 50,000 people come to recuperate each year. A Hot Springs Aquatic Center has been established for provincial and municipal athletes training.

For geothermal cultivation, two fish greenhouses have been completed, with an area of 2,000m^2. Experiments were conducted on the growth of Song Carp, Japanese Koi Carp, White Pomfret, Luo Non, Wuchang Fish and Egypt Beard Blenny. Now geothermal greenhouse pisciculture achieves success with an annual output of 600,000kg Beard Blenny, equal to economic benefits of 5 million yuan. Daqing has become a special fish fry breeding base in Northeast China.

In terms of geothermal planting, the number of geothermal greenhouse raising strawberries, cucumbers, tomatoes and other vegetables has reached 3,000, annual production of 38,000 tons of vegetables. Every year this brings farmers an increase of 100 million yuan income. Daqing has been a fruit and vegetable greenhouse base of Northeast China. The problem of lacking of vegetables in winter in the cold areas has been solved. Meanwhile, the local farmers have successfully found a way to shake off poverty and get rich.

In the way of geothermal tourism, Lindian has won the title of “China Hot Springs Town”, “World Hot Spring Health Base”. The North Hot Spring Leisure Square in Lindian got an award of “China Top Ten Spa”, “Chinese Best Open-air Hot Spring”, “Heilongjiang Hot Spring Tourism Brand” and "China AAAA Area". Lianhuan Lake hot springs spot in Duerbote, which is the exclusive Mongolia medicine bath base, has also received the "Best International Ecotourism Scenic Area" and "China AAAA" title. Petroleum, geothermal resources and wetland in Daqing have become the three brands to attract domestic and foreign tourists. In 2010 Daqing was awarded “China Excellent Ecotourism City". In 2011, Daqing received 9.168 million visitors and the gross income amounts to 3.517 billion yuan. Daqing has become China's well-known tourist boomtown.

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