Transactions on Environment, Energy and Earth Sciences
ISSN: 2960-1924, eISSN: 2960-2300 | Volume 2
ERET 2024

An Overview of Exploitation and Utilization of Shallow Geothermal Energy in Northwest China

Chang Sun *, Xiaolei Ju

China National Engineering Research Centre for Human Settlements, China Architecture Design & Research Group, Beijing, China

* Corresponding Author Email: sunc@cadg.com

Abstract. Geothermal energy, as a non-carbon-based energy, serves as a crucial way to achieve the goal for "carbon reductions in two stages", namely the target of peaking carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060. China is a large country with abundant mesothermal-epithermal geothermal resources. Its national potential geothermal resources account for nearly 8% of those in the world, and geothermal resources have been developed and utilized for nearly 50 years in China. According to incomplete statistics, the geothermal fields in Northwest China accounts for 10% of those in the country, and the stored thermal energy in Northwest China accounts for 3.34% of the total in the country. In order to probe into the potential of geothermal resources in Northwest China and their value in the goal for "carbon reductions in two stages", this paper summarizes the shallow geothermal energy resource endowment in Northwest China, briefly introduces the status quo of shallow geothermal energy exploitation and utilization and existing problems.

Keywords: shallow geothermal energy, Northwest China, exploitation and utilization.

1. Introduction

In 2020, China's total energy consumption was 4.98 billion tons of standard coal equivalent [1] with 8.036 billion tons of carbon dioxide emissions in total. Fossil energy accounts for 85% of primary energy and its annual carbon emission accounts for nearly 90% of the total carbon emissions of the society. In order to achieve the goal for "carbon reductions in two stages", it is imperative to conduct energy restructuring. By now geothermal energy, as one of the five major non-carbon-based energy, has been included in *China's Studies on Carbon Neutrality Framework Roadmap* [2].

Geothermal energy derives from molten magma deep in the earth and the decay of radioactive materials. The temperature and depth of the normal temperature layer in different regions in China are correlated to the density of terrestrial heat flow, thermal conductivity of rocks and soils, geothermal gradient, active fractures, burial depth of the substratum, hydrogeological conditions, average annual temperature, rainfall, and climate [3]. According to the statistics of the Mineral Resources Reserve Administration of the Ministry of Geology and Mineral Resources (MGMR, China), the proven geothermal energy available for utilization is shown in Figure 1. There are 74 geothermal fields in Northwest China, with 144.37 MW stored thermal energy.

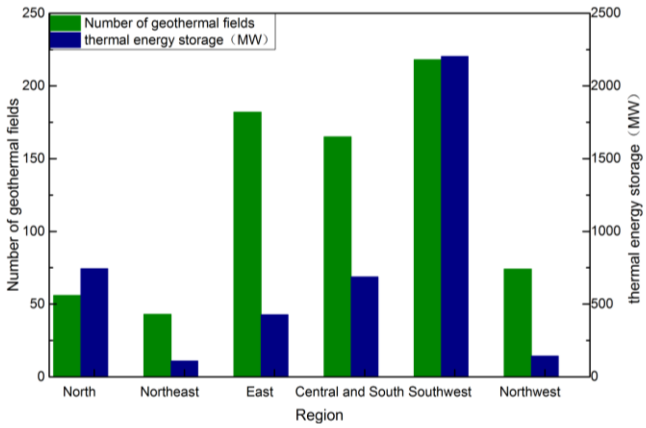

Figure 1. Ascertained geothermal resources in China.

Based on the requirements of the *Renewable Energy Development During the 13th Five-Year Plan Period*, the geothermal energy should be incorporated into the development plans in provinces of Northwest China. The development targets are shown in Table 1.

Table 1. Geothermal Energy Development Targets in Northwest China [4].

Region	**Newly added during the "13th Five-Year Plan" period**			**Accumulated in 2020**		
	Area heated /refrigerated by shallow geothermal energy (10,000 m²)	**Area heated by hydrothermal-type geothermal energy (10,000 m²)**	**Installed power generation capacity (MW)**	**Area heated/ refrigerated by shallow geothermal energy (10,000 m²)**	**Area heated by hydrothermal-type geothermal energy (10,000 m²)**	**Installed power generation capacity (MW)**
Xinjiang	500	250	5	800	350	5
Ningxia	500	/	/	750	/	/
Inner Mongolia	450	1,850	/	950	1,950	/
Gansu	500	100	/	900	100	/

Limited by the technical capability and economic level, shallow geothermal energy is mainly applied in Northwest China. In order to probe into the potential of shallow geothermal resources, this paper gives an overview on the status quo of shallow geothermal resource exploitation, utilization and development.

2. Distribution of shallow geothermal energy resources in Northwest China

The northwestern region of China is a deeply inland region, located north of the Kunlun Mountains-Altun Mountains-Qilian Mountains and the Great Wall, and west of the Greater Khingan Range and Wushao Mountain. It covers Xinjiang Uygur Autonomous Region, Ningxia Hui Autonomous Region, western part of Inner Mongolia Autonomous Region, and northwestern part of Gansu Province [5]. Geothermal energy [6] is a type of energy formed as a result of the perennial temperature difference between the ambient temperature and the temperature at a distance of 1.5m from the earth surface without direct sunlight (thermometer screen), and is the potential energy existing between two temperature fields with different states. Shallow low temperature energy [7] is the earth's internal thermal energy resource existing from the constant temperature zone to the depth of 200m that is of exploitation and utilization value, of which the temperature is below 25°C.

On the basis of the heat storage endowment characteristics, thermal fluid transfer mode, temperature range, and exploitation and utilization mode, the geothermal resources in China are divided into three major types, that is, shallow geothermal energy, hydrothermal-type geothermal resource, and hot dry rock. And hydrothermal-type geothermal resource is categorized into sedimentary basin type and uplift mountain type [8-10]. Sedimentary basins are abundantly distributed throughout Northwest China, and there are Late Cenozoic volcanic groups in the east. In combination with the *distribution of geothermal energy resources in China* [11] and China's *Geothermal Energy Exploitation and Utilization Planning for the 13th Five-Year Plan Period*, the geothermal resource endowment in Northwest China is shown in Table 2.

Table 2. Geothermal Resource Endowment in Northwest China.

Resource Type		**Location**		**Average Geothermal Temperature (°C)**	**Maximum Geothermal Temperature (°C)**
Shallow geothermal resource		East of Northwest China		25~40	50~60
Hydrothermal-type geothermal resource	Medium and low temperature	Sedimentary basin-type geothermal resource	Hulun Buir –Erlian Basin	35~45	50~60
			Ordos Basin	35~40	50~60
			Hexi Corridor	35~40	50~60
			Turpan-Hami Basin	25~40	40~50
			Tarim Basin	35~40	40~50
			Junggar Basin	30~40	40~45
		Uplift mountain-type geothermal resource	Northern Piedmont of Tianshan Mountain	20~30	30~40

About 20 hot springs (25~42°C) are distributed in such places as Kashgar, Yining and Turpan. They shaped up based on pre-Pliocene lava. There are six volcanic piles in the eastern part of Northwest China, respectively at Yimin River-Moke River, Arxan, DalaiNur, Wulanhada and Chahar Right Front Banner. Lots of shallow geothermal energy resources have shaped up based on both pre-Pliocene lava and post-Pliocene lava.

3. Shallow geothermal energy application

By temperature, geothermal resources are divided into high-temperature (>150°C), medium-temperature (90-150°C), and low-temperature (<90°C) geothermal resources. The ways to utilize geothermal resources of different temperatures [16] are shown in the figure. Geothermal resources have been exploited mainly for hot spring bathing in China since ancient times [17]. The exploitation and utilization of geothermal resources in the modern sense started in early 1970s. Gradually, they are directly used for heating, aquaculture, bathing therapy, agriculture, medical purposes, and power generation. A comprehensive exploitation and utilization system has shaped up [18-23], as shown in Figure 2. As shallow geothermal energy is used for heating 10,000 m^2 public buildings, 350-450 tons of carbon dioxide emissions can be reduced per year.

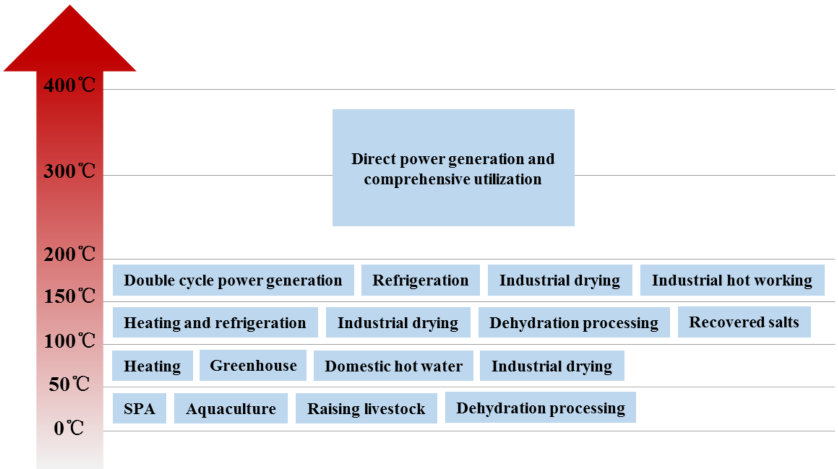

Figure 2. Utilization form of geothermal resources.

In line with the geothermal resource endowment in Northwest China, geothermal resources are mainly used for bathing, aquaculture, livestock raising, dehydration processing, heating, greenhouse, domestic hot water, and industrial drying. With the development of ground source heat pump technology, shallow geothermal energy utilization is now the main way of geothermal energy exploitation and utilization in Northwest China [24].

3.1. Direct utilization

In recent years, the direct utilization of geothermal energy in China has developed rapidly. The annual directly-utilized thermal energy reaches 7.53×10^{13} KJ and total installed capacity reaches 8.9 million KW. The percent of direct utilization ways in the total installed capacity is shown in Figure 3, in which top three direct utilization ways are ground source heat pumps (59%), bathing and swimming (21%), and geothermal heating (15%) respectively [24], nearly consistent with the worldwide geothermal resource utilization ways (Figure 4).

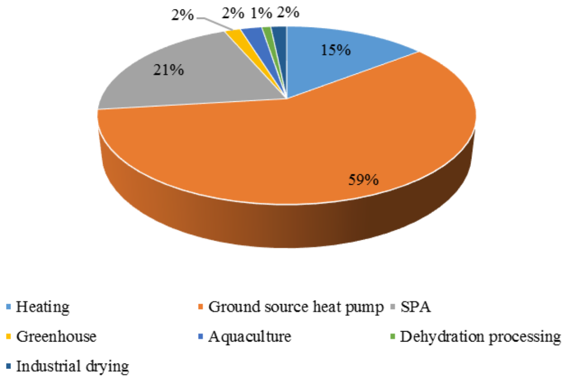

Figure 3. Percentage of installed capacity of geothermal energy direct utilization in total installed capacity in China.

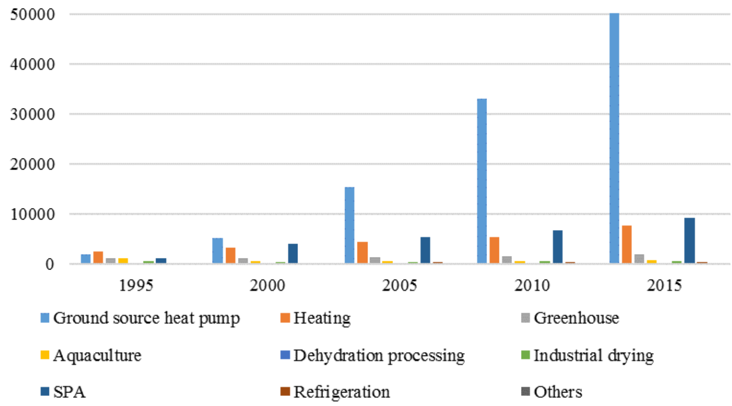

Figure 4. Transformation of installed capacity of geothermal resource utilization modes in the world.

It learns from incomplete statistics that there are 62 hot springs and geothermal anomaly holes in Gansu Province, including seven with medium and low-temperature (from 40℃ to 60℃) hot water, 21 with low-temperature (from 25℃ to 40℃) hot water, and 34 with abnormal hot water (from 15℃ to 25℃). These resources have been developed in Lanzhou City and Tianshui City. Geothermal anomalies appeared in cities such as Jiuquan and Jiayuguan. And there are thermal storage structures in cities including Baiyin, Pingliang, and Dingxi [7,26,27].

In Tianshui, Lanzhou, Dunhuang and some other prefecture-level areas, fracture structures and development are complicated and of large scale, with profound impact. Their thermal storage structures and conditions are excellent. There are abundant underground warm water sources, with a large flow (2,600-3,600 m^3/d) and a water temperature of 28℃-39℃, and the quality water contains microelements or weak radioactive radon. Since these water resources are close to towns, tourist areas, or economic development zones, most of them have been exploited for medical treatment and hot spring bathing. The places such as Jiuquan, Jiayuguan, and Pingliang are under the pressure of high water heads. Therefore, there is large amount of artesian water in these places, where underground warm water sources are abundant and high-quality, but the thermal reservoir has a low temperature (20℃-25℃). Such water is mainly used for domestic drinking, agricultural irrigation, fish farming, and seedling [28,29].

Geothermal water resources are abundant in Xinjiang, but the degree of research is low there, and only a few of such resources have been exploited and utilized. So far geothermal water resources have exploited and utilized in Urumqi, Shihezi, Aksu, and Tashkurgan Tajik Autonomous County. There are six hot springs in Shawan County, Shihezi City, with an average water temperature of 35℃, which are used for bathing.

3.2. Cascade utilization

During the exploitation and utilization of geothermal resources, there are energy conversion losses that result in a continuous decrease in the heat carried by each unit of fluid. In order to enhance the geothermal energy utilization rate, it is proposed that geothermal energy is utilized on a cascaded basis [30], as shown in Figure 5. The geothermal fluid at the outlet is applied to the next temperature cascade after it is utilized at the first cascade. Currently, a majority of commercial organic Rankine cycle modules require a minimum temperature of 93℃ on average. As a result, this temperature is set as the minimum temperature for the first cascade of power generation [31]. Absorption chillers require a geothermal fluid temperature higher than 80℃. In the third cascade, geothermal fluids with a temperature higher than 70℃ are used directly. The specific form of geothermal energy utilization at each cascade is determined according to the actual outlet temperature of geothermal fluids [32].

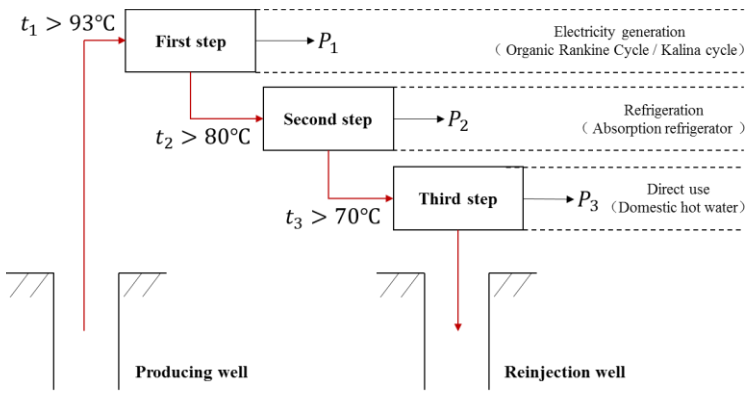

Figure 5. Schematic diagram of typical geothermal energy cascade utilization system.

In the light of the geothermal resource endowment, the highest geothermal heat temperature in Northwest China is less than 70°C, failing to meet the conditions for cascade utilization. During the investigation and survey, I found that some heating projects have different terminals, requiring different water supply temperatures from 70°C to 40°C. Thus, the heat pump technology may be applied to raise the shallow groundwater temperature (50°C) to 70°C for cascade utilization, as shown in Figure 6a. In my opinion, geothermal resources may be used reasonably for different heat use terminals. When it is technologically and economically reasonable and the temperature of water required at the end is high (such as radiator), underground hot water may be utilized after its temperature is raised. When the temperature of underground hot water is up to the temperature of the water required at the end (such as low-temperature floor radiation, fan coils), underground hot water may be directly used for heating, as in Figure 6b. In this way, geothermal resources can be fully utilized, heat pump's heating capacity can be reduced, heat pump's performance coefficient can be increased, and then the system performance coefficient can be improved.

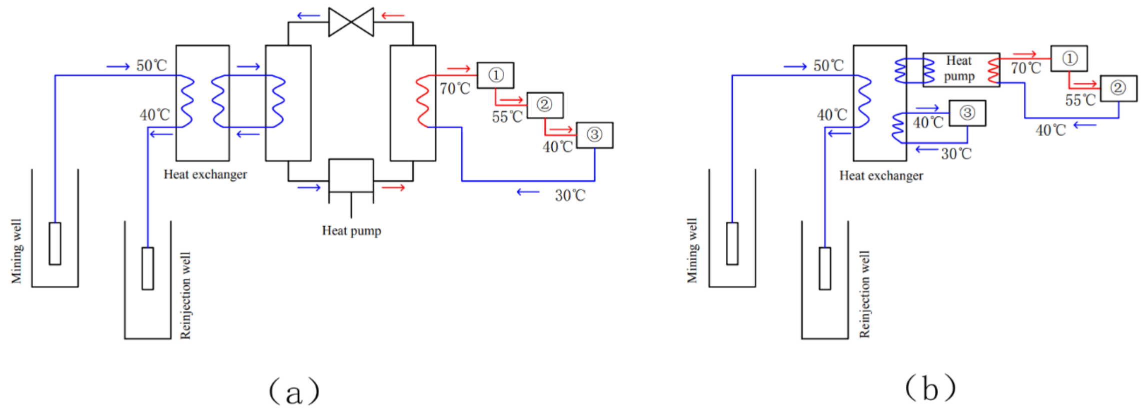

Figure 6. Schematic diagram of cascade utilization of shallow geothermal energy.

3.3. Heat pump technology

The ground source heat pump (GSHP) mechanism originated in Switzerland in 1912, and the heat pump technology formation began in the United Kingdom and the United States [33]. A ground source heat pump system uses the solar energy resources stored by the earth (soil, earth surface or groundwater) as cold and heat source to realize the transfer of low-temperature thermal energy to high-temperature thermal energy by inputting a small amount of high-grade energy (e.g. electrical energy), as shown in Figure 7. Shallow geothermal energy is the source for heat supply in winter and the source for air-conditioning in summer. Shallow geothermal energy heat pump systems are divided into buried-tube GSHP systems and groundwater GSHP systems. Currently, buried-tube GSHP heating technology is the most widely used and technically mature form of engineering application [34]. Relevant data show that the GSHP application area in China has grown from 100,000 m^2 in 2000 to 360,000,000 m^2 in 2014, and the total quantity of GSHP in use has grown geometrically, as shown in Figure 8.

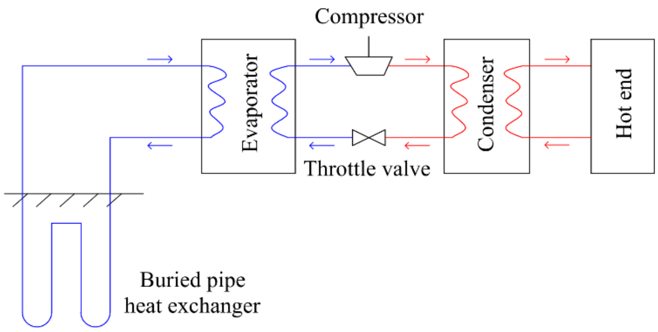

Figure 7. Schematic diagram of cascade utilization of shallow geothermal energy.

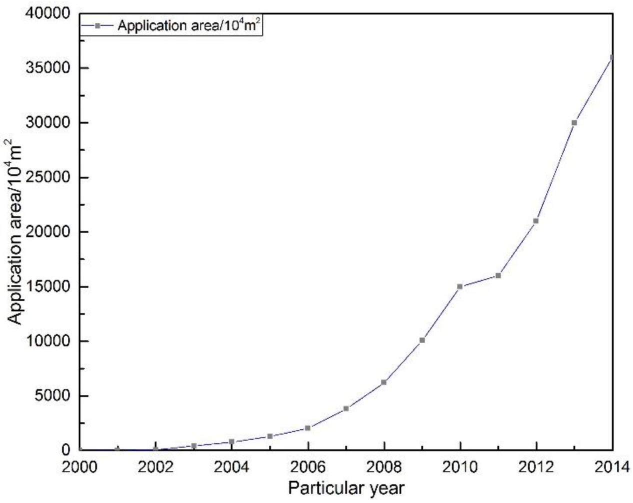

Figure 8. Schematic diagram of cascade utilization of shallow geothermal energy.

The macro judgment of "imbalance and insufficiency" is also applicable to the evaluation of the current situation of shallow geothermal energy development and utilization in Northwest China. Most areas in Xinjiang and Inner Mongolia, especially deserts and areas with extreme water shortage and some extremely cold areas, are not suitable for establishing groundwater source heat pump systems [35]. The earliest exploitation of shallow geothermal energy in Urumqi started in 2008. In addition to groundwater and buried-tube GSHP systems, there are still surface water heat pump systems (two, serving 19,800 m^2) and sewage source heat pump systems (four, serving 171,000 m^2) used for clean heat supply [25].

Shallow low temperature energy has been exploited and utilized in Ningxia [36,37] since the beginning of the 21st century. It has been fully exploited and utilized mainly in Yinchuan [38], where the way of utilization has been gradually converted to buried-tube GSHP from previous groundwater GSHP.

The exploitation and utilization of shallow geothermal energy is in the initial stage in Inner Mongolia. The investigation and evaluation of shallow geothermal energy in Hohhot City was completed in 2013 [39]. Shallow geothermal energy is mainly used for heating and cooling in office buildings of enterprises and public institutions, residential quarters, and shopping malls [25].

The suitable forms, locations and areas of geothermal resource utilization in Lanzhou, Gansu Province are shown in Table 3. A total of 18 GSHP projects have been built in the central urban areas of Lanzhou, serving a total floor area of about 487,000 m^2.

Table 3. Suitable Forms of Geothermal Resource Utilization in Lanzhou [40,41].

Geothermal Resource Utilization	Location		Area (km^2)
Groundwater GSHP	Suitable area	First-order terraced plain area near the bank of Yellow River in the section from Shengou Bridge to Leitan River	25.3
	Relatively suitable area	Qilihe Fault Basin and the second-order area of Yellow River Valley beyond it, Heping Basin, and the plain area of Dingyuan Basin	184.7
Buried-tube GSHP	Suitable area	Liuquan Township in Xigu District; Shajingyi in Anning District - Anningbao; Wuxingping in Qilihe District - Gouya Mountain; Xiaopingzi - Xijinping; Saohu Beach of Qilihe; and Yanchangbu in Chengguan District	240.9
	Relatively suitable area	Xigu City in Xigu District; Anningbao in Anning District -Shilidian; Xiguan in Chengguan District - Sangyuanzi; Heping-Dingyuan Basin	382.5

Heat and cold supply based on Northwest China shallow geothermal energy heat pump technology is summarized in Table 4.

Table 4. Number of GSHP Heat and Cold Supply Projects and Service Areas in Northwest China.

Province	Groundwater GSHP projects		Buried-tube GSHP projects	
	Quantity	Service area (10,000 m^2)	Quantity	Service area (10,000 m^2)
Xinjiang [25]	9	9.38	2	4.05
Ningxia [42]	7	26	6	19
Inner Mongolia [25]	4	37.36	3	26.53
Gansu [43,44]	15	Unknown	3	Unknown

Based on the utilization of geothermal energy in each province, it is found that the shallow geothermal energy in Northwest China is mainly used for cold and heat supply and bathing therapy. Shallow geothermal energy is used directly for heat transfer and GHSP heat supply while underground hot water is used directly for bathing therapy. The geothermal resource exploitation and utilization are still in the initial stage. The status quo of utilization and typical utilization areas are summarized in Table 5.

Table 5. Status Quo of Shallow Low-temperature Energy Utilization in Northwest China and Typical Utilization Areas

Province	Xinjiang	Ningxia	Inner Mongolia	Gansu
Heat supply	Aksu, Taxkorgan	Yinchuan	Hohhot	Lanzhou
Fish breeding and poultry raising	/	/	/	Jiayuguan, Jiuquan, Pingliang
Bathing therapy	Urumchi, Shihezi	/	/	Tianshui, Lanzhou

As a GSHP system works alone, there is a soil temperature field imbalance phenomenon. Though intermittent operation can be adopted to maintain soil temperature field balance, the performance coefficient of heat pump units will be affected due to the reduction of geothermal energy year by year because it is severe cold in Northwest China, where annual demand for heat supply is much greater than that for cold supply. In order to make full use of geothermal energy and improve energy grade, geothermal energy may be used in combination with other renewable energy sources (solar energy, air energy, etc.) to form a multi-energy coupling system to supply heat, cold and domestic hot water. The multi-energy coupling system, which is dominated by shallow geothermal energy in Northwest China, is currently in the stage of research and designated demonstration.

4. Existing problems

After decades of experiments and promotion, the development and utilization of shallow geothermal energy in Northwest China has achieved certain results, but it is still in its infancy. At present, the main problems restricting the development and utilization of shallow geothermal energy in Northwest China are as follows.

4.1. Lack of unity of management functions

The geothermal development and management functions of provinces in Northwest China are scattered in different departments such as land, housing and construction, water conservancy and so on. The overlapping or lack of management system seriously affects the development of geothermal industrialization.

4.2. Loose administrative license

Every province in Northwest China have issued or are carrying out geothermal and other renewable energy development plans. However, the local legislative work lags behind under the background of "double carbon", and the control of administrative license is not rigorous or even missing. The market commercial behaviours of construction enterprises and owners occupy the mainstream of geothermal development resulting in high development risk. Many enterprises did not conduct sufficient feasibility studies on geothermal conditions and water balance in the early stage resulting in problems such as ineffective groundwater recharge in some projects.

4.3. Prospecting delay

The degree of geothermal resource exploration in Northwest China is relatively backward, and the evaluation of geothermal resource potential in many places is still at the estimation level. The survey accuracy and depth lag behind the demand for development and utilization, which is far from meeting the needs of the market. Many ground source heat pump projects did not carry out geothermal survey before project design, as a result, a large number of important geological basic data under construction and completed missed.

4.4. Engineering design limitation

Not only the local climatic conditions should be considered in the design of geothermal engineering system, but also the comprehensive elements such as load demand and use characteristics of the system. Geothermal design in Northwest China is generally lack of overall conception, which has strong limitations to meet immediate and special purposes. Some ground source heat pump engineering designs do not fully consider the balance of heat released and absorbed from the soil throughout the year, resulting in the continuous increase or decrease of the underground temperature field after putting into operation, and the energy efficiency of the system in summer or winter is greatly reduced [25].

4.5. Quality control disorder

At present, the design and construction of ground source heat pump system lacks mandatory standards under the "double carbon" background. The project generally refers to provisions of “Technical code for ground-source heat pump system” (GB50366), which does not have detailed requirements for construction quality control. Most enterprises do not have specified strict quality control measures; therefore, the project lacks quality control basis and it is difficult to strictly control the construction quality [25].

4.6. Inadvertent reinjection measures

Full recharge of geothermal tail water is an important measure to ensure the sustainable utilization of geothermal energy. Many projects do not recharge geothermal water in time, resulting in an imbalance between exploitation and recharge, and a drop in water level, which greatly reduces the sustainable utilization life of the mining and irrigation system. In the early stage of development and utilization, the reinjection in Yinchuan is ideal in a short time, but after one or two years, the reinjection rate gradually decreases, the effect of groundwater recycling is poor, and the groundwater that cannot be reinjected is directly discharged on the surface, resulting in great waste of groundwater resources and environmental pollution.

4.7. High utilization cost

In Northwest villages and towns, residents mostly use decentralized heating. The average heating price is 4.0 ~ 5.0 yuan / m^2 per month, which also forms the price that rural residents can afford psychologically. The average price of geothermal heating is 5.5 ~ 6.5 yuan / m^2 per month. If there is no preferential financial subsidy from the government, user acceptance is bound to be low.

The utilization of shallow geothermal energy in Northwest China has problems in survey, design, construction, management and cost. It is necessary to speed up the introduction of local legislation and mandatory standards based on the "double carbon" background. Relevant personnel, especially professional designers, should strengthen their understanding of the characteristics and technology of abundant shallow geothermal energy resources on the surface of the earth's crust. The functional departments of geothermal development management should strengthen communication and coordination, uniformly manage and examine the exploration and evaluation, engineering design, long-term monitoring of geological environment and project operation data in the later stage, to promote the development and utilization of shallow geothermal energy actively.

5. Conclusions

Under the background of "double carbon", it is urgent and necessary to speed up the development and utilization of shallow geothermal energy resources in Northwest China.

Northwest China is rich in shallow geothermal energy resources. Most geothermal resources are sedimentary basin hydrothermal geothermal resources, and there are shallow geothermal resources formed by lava of Late Cenozoic volcanic groups in the east.

Shallow geothermal energy in Northwest China is mainly used for refrigeration, heating, SPA and recuperation. Underground water and buried pipes ground source heat pump projects are usually used for cooling and heating. According to incomplete statistics, there are 35 underground water ground source heat pump projects in Northwest China, with a service area of 727,400 m^2, and 14 buried pipe ground source heat pump projects, with a service area of 495,800 m^2. The total heating area of clean energy in Northwest China is about 1,901,000 m^2.

In practical engineering, shallow geothermal energy can be combined with renewable energy such as solar energy, air energy and biomass energy to form a multi energy coupling distributed energy system.

There are many problems in the utilization of shallow geothermal energy in Northwest China, such as management, survey, design and construction. Engineering and technical personnel, government functional departments and standard setting units should strengthen their understanding, learning and support of shallow geothermal energy, to make the system design, development, utilization, monitoring and management from beginning to end, and promote the comprehensive promotion and application of shallow geothermal energy in Northwest China.

Acknowledgments

This work was financially supported by National Key Research and Development Plan of China (Project Code: 2020YFD1100505-03).

References

[1] National Bureau of Statistics of China. Statistical bulletin of the People's Republic of China on national economic and social development in 2020. 2021-02-28.

[2] Z. L. Ding. Research on China's carbon neutralization framework Roadmap, J. China Industry & Information Technology. 2021, (08): 54-61.

[3] W. S. Wei, N. B. Li, G. S. Zheng, et al. Study on genetic mechanism and control conditions of shallow geothermal energy in China, J. Urban Geology. 2020, 15(01): 1-8.

[4] C. H. Guan, Z. Zhao, Y. Liu, et al. Shallow geothermal energy and clean heating -- international experience, Chinese practice and development path, Scientific and Technical Documentation Press, Beijing, 2021.

[5] Information on http://www.gov.cn/guoqing/2005-07/27/content_2582640.htm

[6] Y. B. Luan, G. S. Zheng, W. S. Wei. Review of the shallow geothermal energy ersources development and utilization, J. Geology and Exploration. 49(2) (2013) 0379-0383.

[7] W. S. Tian, B. Zhou. Primary analysis on characteristics of geothermal resources of shallow groundwater in Lanzhou city, J. Ground Water. 33(5) (2011) 6-10.

[8] W. J. Lin, Z. M. Liu, W. L. Wang, et al. The assessment of geothermal resources potential of China, J. Geology in China. 40(1) (2013) 312-321.

[9] J. K. Liu. The assessment of geothermal resources potential of China, J. China High Tech Enterprises. 33 (2016) 134-136.

[10] Y. L. Yin. The assessment of geothermal resources potential of China, J. Science and Technology & Innovation. 5 (2018) 57-58.

[11] Information on https://www.osgeo.cn/map/mb4cf

[12] Information on http://www.nea.gov.cn/2017-02/06/c_136035635.htm

[13] J. Y. Wang. Geothermy and its application, Science Press, Beijing, 2015.

[14] G. L. Wang, W. Zhang, J. Y. Liang, et al. Evalution of geothermal resources potential in China, J. Acta Geoscientica Sinica. 38(4) (2017) 449-450.

[15] G. L. Wang, Y. G. Liu, X. Zhu, et al. The status and development trend of geothermal resources in China, J. Earth Science Frontiers. 27(1) (2020) 1-9.

[16] F. Feng, L. Zhang. Introduction to new energy technology and Application, second ed., Chemical Industry Press Co.,Ltd, Beijing, 2016.

[17] G. L. Qiu, X. L. Zhang, K. Wu. Study on the present situation and problems of geothermal resources development and utilization in Shaanxi province, J. China Non-metallic Mining Industry Herald. S1 (2018) 70-73.

[18] M. Pujol, P Ricard-L, G Bolton. 20 years of exploitation of the Yarragadee aquifer in the Perth Basin of Western Australia for direct-use of geothermal heat, J. Geothermics, 57 (2015) 39-55.

[19] C Melissa, M. D. Sarah, A. W. Brian. A history of geothermal direct use development in the Taupo Volcanic Zone, New Zealand, J. Geothermics, 59 (2016) 215-224.

[20] N NAILI, M HAZAMI, I ATTAR. Assessment of surface geothermal energy for air conditioning in northern Tunisia: direct test and deployment of ground source heat pump system, J. Energy and Buildings, 111 (2016) 207-217.

[21] A ASLAN, B YÜKSEL, T AKYOL. Energy analysis of different types of buildings in Gonen geothermal district heating system, J. Applied Thermal Engineering, 14(31) (2011) 2726-2734.

[22] K KERRIGAN, E JOUHARA-H-G. Heat pipe-based radiator for low grade geothermal energy conversion in domestic space heating, J. Simulation Modelling Practice and Theory, (19) (2011) 1154-1163.

[23] A KYRIAKIS-S, L YOUNGER-P. Towards the increased utilization of geothermal energy in a district heating network through the use of a heat storage, J. Applied Thermal Engineering, (94) (2016) 99-110.

[24] Information on http://www.most.gov.cn/kjbgz/201203/W020120309590813594101.pdf

[25] G. L. Wang, et al. Investigation and evaluation of shallow geothermal energy in major cities in China, Science Press, Beijing, 2019.

[26] Z. L. Zeng. Present situation and exploration direction of geothermal resources in Longdong area, Gansu province. J. Ground Water. 32(3) (2010) 58-114.

[27] Y. K. An, Z. X. Sun, B. X. Li. Distribution and exploitation of geothermal resources in Gansu province, J. Acta Geologica Gansu. (02) (2005) 70-75.

[28] Y. H. Wen. Tourism resource valuation and tourist experience of hot spring in Gansu province, M. Lanzhou University. 2011.

[29] B. Zhou. Characteristics of geothermal resources in main cities of Gansu Province and suggestions on development and protection, J. Ground Water. 33(01) (2011) 54-57.

[30] E. PASTOR-MARTINEZ, C. RUBIO-MAYA, V. AMBRIZDÍAZ. Energetic and exergetic performance comparison of different polygeneration arrangements utilizing geothermal energy in cascade, J. Energy Conversion and Management. (168) (2018) 252-269.

[31] L. C. Liu, T. Zhu, N. Gao. A review of modeling approaches and tools for the off-design simulation of organic Rankine cycle, J. Journal of Thermal Science. 4(27) (2018) 305-320.

[32] K. SALHI, M. KORICHI, M. RAMADAN-K. Thermodynamic and thermo-economic analysis of compression absorption cascade refrigeration system using low-GWP HFO refrigerant powered by geothermal energy. J. International Journal of Refrigeration. (94) (2018) 214-229.

[33] Y. Wu. The research on environment problems and key technology of shallow geothermal energy, M. China University of Geosciences. 2014.

[34] G. L. Wang, X. Yang, L. Ma, et al. Status quo and prospects of geothermal energy in heat supply, J. Huadian Technology. 43(11) (2021) 15-24.

[35] W. J. Lin. The study of thermal regulation and storage capacity in shallow geological environment and it's avalibility, M. Chinese Academy of Geological Science. 2012.

[36] P. C. Zhang, X. D. Chu. Feasibility analysis of the development and utilization of shallow geothermal energy in Ningxia, J. Ningxia Engineering Technology. 16(02) (2017) 165-167.

[37] Z. Liu, Z. Y. Hu, C. Yang, et al. Study on thermal response test of ground source heat pumps in Yinchuan city, J. Ningxia Engineering Technology. 12(03) (2013) 245-247.

[38] Y. F. Chen. Thermal response test of buried pipe and ecaluation of shallow geothermal energy resource in key cities of Ningxia, M. Chang'an University. 2012.

[39] F. G. Yan. Investigation and evaluation report on shallow geothermal energy in Hohhot. Inner Mongolia Geological Investigation Institute. 2013.

[40] L. S. Wei, L. P. Zhang, T. Wang, et al. Anlysis of geothermal geological conditions and resources exploitation potential in Lanzhou city, J. Geological Survey of China. 5(02) (2018) 45-50.

[41] L. S. Wei, Z. F. Xie, L. P. Zhang, et al. Exploration report of geothermal resources in Lanzhou City. The second geological and Mineral Exploration Institute of Gansu geological and mineral exploration and Development Bureau. 2017.

[42] C. Yang. Research on the comprehensive evaluation of shallow geothermal energy resource in Yinchuan, M. Chang'an University, 2017.

[43] Y. H. Sun, W. J. Shen. "Hot pulse" surging in Jincheng -- Interpretation of the exploration, development and utilization of geothermal resources in the central urban area of Lanzhou. China Mining News.

[44] Z. H. Liu. Lanzhou is rich in geothermal resources and has great prospects for utilization, J. Gansu Energy. (2005) 43-44.

[45] C. Yang, H. Qian, Z. Liu, et al. Analysis on development and utilization prospect of ground source heat pump with buried pipe in Yinchuan City. Qingdao. 2014.